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Research paper

Exploring the development of pre-service science teachers' self-efficacy beliefs through guided inquiry-based laboratory instruction: The role of cognitive styles

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ABSTRACT

Inquiry-based instruction fosters 21st-century skills, yet its effect on science teaching self-efficacy beliefs (STSEB), particularly in relation to cognitive style differences, remains underexplored. This study investigates changes in STSEB among six pre-service science teachers (PSTs) with distinct cognitive styles using a guided inquiry-based laboratory approach. Bandura's four sources of self-efficacy provide the theoretical framework. Participants' cognitive styles were determined using the Group Embedded Figures Test, with two participants identified as field-independent and four as field-dependent. Data were collected through focus group interviews, semi-structured interviews, and self-reflection forms. Descriptive analysis showed that STSEB improved across all participants, with mastery experiences having the strongest impact. For field-dependent PSTs, vicarious experiences, verbal persuasion, and emotional states were also notably influential. These results indicate that guided inquiry-based instruction can enhance STSEB, particularly when cognitive style differences are considered. The findings offer implications for teacher education programs aiming to support self-efficacy through differentiated, cognitively responsive teaching strategies.

1. Introduction

Contemporary educational reforms focus on developing 21st-century competencies, such as critical thinking, inquiry, problem-solving, and creativity (NRC, 1996). Inquiry-based instructional approaches support these goals by engaging students with real-world scientific problems (Beck & Blumer, 2021). Science laboratories provide natural settings for these methods (Hofstein & Lunetta, 2004). Therefore, inquiry-based laboratory practices help develop students' scientific reasoning and skills (Sen & Sezen Vekli, 2016). However, studies report that science teachers often struggle to adopt these practices effectively (Fitzgerald et al., 2017; Kaya et al., 2021). Low self-efficacy beliefs in science teaching are often cited as a key barrier (Lakshmanan et al., 2011; Seung et al., 2019).

Self-efficacy is defined as individuals' beliefs in their ability to perform specific tasks (Bandura, 1997). It greatly influences teachers' instructional strategies and persistence in challenging environments (Pajares, 2002). High self-efficacy is linked to the use of student-centered, inquiry-oriented teaching approaches and better student outcomes (Kaya et al., 2021; Seneviratne et al., 2019). Research indicates that professional development and instructional experiences strengthen teachers' science teaching self-efficacy. This is especially true when leveraging Bandura's four sources of efficacy: mastery experiences, vicarious experiences, verbal persuasion, and physiological and affective states (Atasoy & Cakıroglu, 2018; Bandura, 1997; Lotter et al., 2018).

While educational reforms emphasize 21st-century skills, they also highlight the importance of individual differences. Science curricula in many countries strive to cultivate scientific literacy in all individuals (Millar, 2006; Turkish Ministry of Education [TME], 2018). Designing interventions to enhance the STSEB of science teachers and pre-service teachers in inquiry-based labs requires careful consideration of these differences. Cognitive styles, particularly the distinction between field-dependent and field-independent, significantly impact academic performance (Tinajero & Paramo, 1998a). Examining inquiry-based lab interventions aimed at enhancing STSEB through the lens of cognitive styles may therefore offer valuable insights for development.

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2. Literature review

This section outlines three concepts central to the theoretical framework: (1) PSTs' self-efficacy beliefs, (2) inquiry-based teaching, and (3) cognitive styles. Initially, it considers self-efficacy and its influence on teaching. Inquiry-based instructional practices, as advocated in science education, are discussed next. Finally, the section examines cognitive styles—addressing how individual differences among PSTs intersect with self-efficacy development.

2.1. Self-efficacy beliefs

Self-efficacy and science teaching self-efficacy beliefs (STSEB) form the foundation of this study. Based on Bandura's (1977) social cognitive theory, self-efficacy refers to individuals' beliefs in their ability to organize and execute actions needed to achieve outcomes. These beliefs shape motivation, persistence, and emotional regulation (Pajares, 2002). Bandura identified two dimensions—personal self-efficacy and outcome expectancy—and four key sources: mastery experiences, vicarious experiences, verbal persuasion, and physiological or affective states (Bandura, 1997). Among these, mastery experiences are most influential (Kleppang & Steigen, 2023; Nordin et al., 2018). In teacher education, Palmer (2006) expanded this framework to include cognitive content mastery (understanding subject matter) and cognitive pedagogical mastery (learning how to teach it). Both strengthen STSEB (Zundans-Fraser & Lancaster, 2012).

In education, self-efficacy is a teacher's belief in their ability to complete specific teaching tasks effectively in a given context (Tschannen-Moran et al., 1998). Higher self-efficacy is linked to greater perseverance and instructional quality. It also builds confidence in both student abilities and teaching practice (Woolfolk et al., 2009). Research shows that teachers with strong self-efficacy develop students with similar beliefs (Hoy & Spero, 2005). On the other hand, low STSEB is linked to negative attitudes toward science teaching and a preference for teacher-centered instruction. High STSEB aligns with student-centered and inquiry-based approaches (Kaya et al., 2021; Marshall et al., 2009; Wang et al., 2015).

Self-efficacy tends to stabilize over time (Bandura, 1997). Pre-service teachers (PSTs), however, have more flexible beliefs (Clark & Newberry, 2018). Teacher education is therefore a crucial period for developing self-efficacy (Atasoy & Cakıroglu, 2018; Kıran, 2022). Prior research has improved PSTs' self-efficacy mainly through science content and methods courses (Menon & Sadler, 2016; Seung et al., 2019). Fewer studies have explored science laboratory contexts, which provide rich mastery experiences (Akyol & Taş, 2024; Kıran, 2022).

This study addresses the gap by examining how guided inquiry-based learning and teaching laboratory (GILTLab) instruction influences STSEB development in PSTs. It also investigates how cognitive styles shape these developments. This provides insights on accommodating individual differences through differentiated, inquiry-based instructional approaches in science teacher education.

2.2. Inquiry-based teaching

Inquiry-based science instruction (IBI) uses strategies that actively engage students in constructing scientific understanding (NRC, 2012). The National Research Council (2000) lists five key elements of effective IBI. These include posing questions, prioritizing evidence, constructing explanations from evidence, connecting explanations to prior scientific knowledge, and communicating findings. These practices reflect scientific reasoning and are increasingly highlighted in science teacher education. In this study, GILTLab was used to promote these elements among pre-service science teachers (PSTs).

Recent research highlights both the benefits and challenges of IBI. While teachers often hold positive attitudes toward IBI, they report difficulties with its implementation, especially regarding methodology (Guerrero & Bautista, 2023). Novice teachers are less likely to apply IBI due to limited experience (Karklelytė, 2023), but training can improve their awareness and pedagogical competence (Şensoy et al., 2024). IBI has been shown to enhance students' scientific process skills, conceptual understanding, and academic performance (Kersting et al., 2023; Twizeyimana et al., 2024). In teacher education, IBI improves both content knowledge and instructional skills (Strat & Henriksen, 2023), and teachers' self-efficacy in IBI correlates with classroom implementation quality (Toma et al., 2024).

IBI can vary in teacher guidance. Structured inquiry offers a set procedure. Open inquiry allows full autonomy. Guided inquiry combines structure with student-directed exploration (Olson & Loucks-Horsley, 2000). Guided inquiry suits PSTs because it promotes deeper understanding, inquiry competence, and teaching confidence (Aditomo & Klieme, 2020; Blanchard et al., 2010).

This study uses a GILTLab to explore how STSEB develops in PSTs. Methodological and procedural details of the GILTLab are discussed in the following sections.

2.3. Cognitive styles

Cognitive styles refer to individuals' consistent ways of perceiving and processing information, influencing learning and problem-solving (Riding & Rayner, 1998). Witkin's (1971) field dependence–independence model, widely used in educational psychology, distinguishes between field-independent learners—who analyze and separate relevant details from complex contexts—and field-dependent learners, who rely more on external cues and social contexts (Guisande et al., 2007; Witkin & Goodenough, 1976). These styles exist along a continuum, and neither is inherently superior (Saracho, 1997). Unlike cognitive ability, which reflects innate potential, cognitive style refers to preferred ways of processing information that shape how that potential is realized (Riding & Rayner, 1998).

Recent studies indicate that field-independent students exhibit higher science literacy self-efficacy, and that cognitive style significantly predicts these beliefs (Sahin & Ates, 2020). In STEM fields, field-independent individuals tend to exhibit stronger analytical skills, while field-dependent individuals tend to show superior contextual understanding. Recognizing this diversity in instructional design can enhance academic achievement (Bacotang, 2023). Although field-dependent students generally possess lower academic self-efficacy, appropriate instructional support can enable them to perform on par with field-independent peers (Danili & Reid, 2004; López-Vargas et al., 2025; Sahin & Sasmaz Oren, 2022).

Cognitive styles mediate how individuals interpret experiences that inform their self-efficacy beliefs (Bandura, 1997; Riding & Rayner, 1998). Theoretically, field dependence–independence can shape how Bandura's (1997) four sources of self-efficacy are activated during inquiry-based instruction. Field-independent learners are more likely to derive a sense of efficacy from mastery experiences, as they engage in independent experimentation and reflection (Danili & Reid, 2004; Witkin & Goodenough, 1976). field-dependent learners, who are more socially attuned, may be more responsive to vicarious experiences and to verbal persuasion (Guisande et al., 2007; van Dinther et al., 2011). Additionally, their greater sensitivity to interpersonal feedback may intensify emotional and physiological states, amplifying either confidence or anxiety during inquiry tasks (Witkin & Goodenough, 1976). Consequently, the same instructional experience may enhance self-efficacy through different psychological pathways depending on cognitive style. Understanding these differentiated mechanisms is essential for designing inclusive inquiry-based environments that foster STSEB across diverse learners.

However, while these theoretical explanations suggest a meaningful relationship between cognitive style and self-efficacy development, empirical studies directly examining this link remain limited. Although the influence of cognitive style on academic achievement and learning preferences has been extensively explored, few studies have examined its role in the development of self-efficacy beliefs (Sahin & Ates, 2020). Addressing this gap, the present study investigates how cognitive styles interact with self-efficacy formation, contributing to differentiated approaches in teacher education.

2.4. The present study

A substantial body of research highlights that science teachers frequently struggle to implement inquiry-based instructional methods effectively (Capps & Crawford, 2013; Kaya et al., 2021), often due to low self-efficacy beliefs in science teaching (Lakshmanan et al., 2011; Seung et al., 2019). In contrast, teachers with high self-efficacy are more likely to consistently adopt inquiry-based strategies and do so with greater confidence (Alqawasmi et al., 2023; Sen & Sezen Vekli, 2016; Seneviratne et al., 2019). As inquiry-based instruction is central to developing students' 21st-century competencies, enhancing teachers' self-efficacy is a critical prerequisite for reform-oriented science teaching.

The literature suggests that pre-service teachers' self-efficacy is more susceptible to change than that of experienced teachers (Clark & Newberry, 2018; Greco et al., 2018). Efforts to bolster pre-service teachers' STSEB have primarily occurred in science content courses (Menon & Sadler, 2016) or methods courses (Atasoy & Cakıroglu, 2018; Seung et al., 2019). However, there is a scarcity of studies examining the impact of guided inquiry-based practices in science laboratories on the development of pre-service teachers' self-efficacy (Akyol & Taş, 2024; Kyriazis et al., 2025; Kıran, 2022).

This study addresses a gap in the literature by implementing a 14-week science laboratory intervention grounded in Bandura's (1997) four sources of self-efficacy—mastery experiences, social modeling, verbal persuasion, and emotional states. Unlike previous research, this intervention aimed to enhance PSTs' self-efficacy beliefs by enabling them to assume both teacher and student roles. Despite the growing focus on individual differences in instructional design (López-Vargas et al., 2025; Millar, 2006), the impact of cognitive styles on self-efficacy development, particularly within inquiry-based teaching, remains underexplored (Sahin & Ates, 2020). By examining how PSTs with varying cognitive styles respond to this intervention, the study assesses the inclusivity of instructional designs for individual differences, thereby enhancing understanding of self-efficacy development from both instructional and individual-difference perspectives. In particular, the study explores how PSTs develop STSEB through participation in the GILTLab. Guided by Bandura's framework, the research focuses on the roles of mastery experiences, vicarious experiences, verbal persuasion, and physiological and affective states, framed by the following questions.

1. How does the GILTLab affect PSTs' science teaching self-efficacy beliefs, particularly in relation to personal science teaching self-efficacy and outcome expectancy?
2. What are the similarities and differences in the sources of self-efficacy beliefs that contribute to these two components?
3. How do these sources differ for PSTs with distinct cognitive styles, particularly regarding personal science-teaching self-efficacy and outcome expectancy?

3. Method

3.1. Research design

This study employed a holistic multiple-case study design to investigate how PSTs with different cognitive styles experienced changes in their STSEB during the GILTLab intervention. Cognitive styles (field-dependent/field-independent) were the focal point of the research. A case study, as a qualitative design, allows for an in-depth exploration of phenomena within real-life contexts, particularly when context significantly influences the phenomenon (Merriam, 1998; Yin, 2014). Each PST was regarded as an individual case, with cognitive style as a case attribute. Participants were closely examined throughout the 14-week GILTLab process, followed by a comparative analysis based on cognitive style, resulting in a holistic multiple-case study design.

For cross-case comparisons, Yin's (2014) cross-case synthesis strategy was utilized. Each case was analyzed in depth, identifying patterns, similarities, and differences relative to cognitive styles. Additionally, Bandura's (1997) four sources of self-efficacy (mastery experiences, vicarious experiences, verbal persuasion, and physiological/emotional states) were integrated into the analysis through pattern matching, enhancing the interpretation of findings within the theoretical framework and strengthening both within-case depth and cross-case comparisons.

3.2. Study group

The study group comprised six PSTs in the third year of a Science Teacher Education program at a mid-sized university in western Turkey. Criterion sampling, a purposive technique, was employed to select participants with relevant characteristics (Patton, 2002). The primary criterion required participants to have completed a Science Teaching Laboratory Practices I course, taught by one of the researchers, in which a guided inquiry-based laboratory approach was implemented. This prior course served as a pilot study for the current research.

The present study took place within the Science Teaching Laboratory Practices II course, with an equal gender distribution (three female and three male PSTs) and diverse academic achievement levels, ages, and cognitive styles. Participants were coded S1-S6, and their cognitive styles were classified as field-independent (FDI) or field-dependent (FD), as detailed in Table 1. Academic achievement levels were based on cumulative Grade Point Average (GPA) from the previous semester, on a 4.00 scale.

Although the study involved six participants, this number was sufficient to ensure case adequacy and data saturation within the holistic multiple-case design. Since descriptive analysis was used, with themes and categories predetermined from the literature (Bandura, 1997; Enochs & Riggs, 1990), the goal was to represent the full range of data within an existing theoretical framework rather than to generate new themes. Consistent with Yin (2014), data saturation was considered reached when no new information emerged across cases and patterns began to converge.

3.3. Data collection tools

Self-efficacy beliefs were examined through semi-structured interview forms, focus group interviews, and a self-critique paper. Although established instruments, such as the Science Teaching Efficacy Belief Instrument (STEBI), exist for measuring STSEB, we deliberately opted not to use standardized scales. This choice was made because such tools may not fully encapsulate the context-specific and role-based experiences of participants in a guided inquiry-based laboratory setting, where they fluctuated between student and teacher roles. Reflection-based instruments enabled a more nuanced, contextually grounded examination of participants' perceptions.

Table 1
PSTs Profile.

PSTs Code	Gender	Age	GPA	Cognitive Styles
S1	Female	21	2.80	FDI
S2	Female	22	2.80	FD
S3	Male	20	2.96	FDI
S4	Male	21	2.47	FD
S5	Female	21	3.00	FD
S6	Male	21	2.86	FD

Although standardized scales such as the STEBI provide validated quantitative measures, they may not capture role-dependent fluctuations in self-efficacy beliefs within dynamic inquiry settings. Therefore, reflection-based instruments were employed to obtain in-depth, context-specific insights, while maintaining conceptual alignment with the two STEBI dimensions—personal science teaching self-efficacy (PSTSE) and outcome expectancy (OE)—and with Bandura's (1997) four sources of efficacy. This approach emphasizes analytic rather than statistical generalization (Yin, 2014), enhancing interpretive depth while preserving theoretical comparability with prior studies.

3.3.1. Focus group interview

One of the qualitative data collection tools used in this study was focus group interviews. Prior to the intervention, a preliminary focus group discussion was conducted with participants, during which they were asked questions related to the two dimensions of STSEB, as outlined in the STEBI developed by Enochs and Riggs (1990) for pre-service science teachers. These two dimensions align with Bandura's (1977) two key components of self-efficacy beliefs: (1) personal efficacy and (2) outcome expectancy. The personal science teaching self-efficacy belief (PSTSE) dimension focused on the question: *"Do you believe you can effectively and successfully teach science to middle school students? Why?"* For the science teaching outcome expectancy (STOE) dimension, participants were asked, *"Do you believe that your science teaching will contribute to your students' effective understanding and success in science? Why?"* Additionally, to identify the factors influencing participants' sources of self-efficacy, they were asked: *"What factors have the greatest impact on your confidence in science teaching? For example, personal experiences, role models, feedback on your teaching success, or emotional states (e.g., anxiety, stress, confidence, etc.)*. The development of these questions was informed by theoretical explanations of STSEB (Bandura, 1977) and existing literature (Atasoy & Cakıroglu, 2018; Enochs & Riggs, 1990). The final version of the interview protocol was refined through expert consultation with a science education specialist experienced in self-efficacy research.

The focus group interview was conducted at the beginning of the study to explore participants' initial self-efficacy beliefs and the sources influencing them. To address potential peer influence inherent in group settings, individual semi-structured interviews were also conducted after each instructional activity throughout the study. This combination of data collection methods enabled us to capture both shared narratives shaped by group dynamics and unique individual reflections.

3.3.2. Semi-structured interview forms

Individual semi-structured interviews were conducted after each instructional session to monitor changes in participants' STSEB. The development of the interview questions was informed by relevant literature (Atasoy & Cakıroglu, 2018; Bandura, 1977; Enochs & Riggs, 1990), and the final version was refined with expert feedback from a science education researcher specializing in self-efficacy beliefs.

In addition to the questions used in the focus group interviews, the semi-structured interviews included questions that specifically examined the impact of self-efficacy sources on each dimension of self-efficacy beliefs. Participants were also asked to reflect on how their responses evolved from previous interviews. For example, participants were asked, *"As a pre-service teacher, do you believe you can help your students effectively understand and succeed in science?"* Follow-up questions were used to explore their beliefs: Has your belief changed compared to your response in the previous interview? If your belief has changed, how has it changed? If your belief has changed, what do you think caused this change? If your belief has not changed, why is this consistency? This approach enabled a longitudinal analysis of participants' evolving self-efficacy beliefs, providing insights into the mechanisms that influenced these changes throughout the study.

3.3.3. Self-critique paper

After each instructional session, participants completed a self-critique paper with seven structured questions designed to elicit their beliefs about their STSEB. The items were developed based on Bandura's (1977) framework and related literature (Atasoy & Cakıroglu, 2018; Enochs & Riggs, 1990), and were reviewed by an expert for clarity. The prompts explicitly targeted Bandura's four sources of self-efficacy: mastery experiences (strengths and weaknesses), vicarious experiences (observations of peers), social persuasion (peer and instructor feedback), and physiological/affective states (reasons for weaknesses and coping strategies). While reflection was the medium, the structured focus ensured that the instrument primarily captured participants' STSEB.

3.3.4. Group Embedded Figures Test

In this study, the Group Embedded Figures Test (GEFT), developed by Witkin et al. (1971), was used to determine whether students exhibited field-dependent or field-independent cognitive styles. The GEFT requires students to identify a target shape within a complex visual context consisting of three sections. The first section contains seven items, while the other two sections each include nine items. The first section serves as a practice phase, ensuring students are familiar with the task format. As a result, test scores range from 0 to 18.

Following the original GEFT manual (Witkin et al., 1971), participants scoring above the sample mean were classified as field-independent, and those scoring below the mean as field-dependent. This mean-based cut-off approach, recommended in the manual and widely adopted in subsequent research (Cakan, 2013; Cataloglu & Ates, 2014; Tinajero & Páramo, 1998), was used in the present study to distinguish between cognitive styles. The Turkish adaptation of the GEFT was conducted by Cakan (2013), who reported a Cronbach's alpha coefficient of 0.82, indicating high reliability.

Although cognitive style is theoretically considered a continuum (Kogan, 1987, as cited in Saracho, 1997), this binary classification is commonly used in GEFT-based research to facilitate group comparisons (Tinajero & Páramo, 1998; Witkin et al., 1971). However, it is acknowledged that such a dichotomous approach may not fully capture the nuanced variations across individuals. Therefore, this limitation was taken into account when interpreting the findings.

3.4. GILTLab intervention

The instructional design of this study was implemented through the *Science Teaching Laboratory Practices II* course, developed in alignment with the study's objectives. Instruction was structured around Lawson's (1995) hypothetico-deductive reasoning cycle, which involves proposing a causal hypothesis, designing an experiment to test it, predicting outcomes, conducting the experiment, and comparing predicted and observed results. This cycle mirrors the core components of inquiry-based teaching as outlined by the NRC (2000).

The course design was also informed by Bandura's (1977) four sources of self-efficacy—mastery experiences, vicarious experiences, verbal persuasion, and physiological/emotional states—which were systematically integrated into course activities to promote pre-service science teachers' STSEB development. A distinguishing feature of the design was the role alternation model: throughout the 14-week intervention, PSTs actively participated as both teachers and students, fostering reflection and deeper pedagogical insight from dual perspectives.

To support mastery experiences, PSTs developed guided inquiry-based lesson plans, implemented lessons using Lawson's hypothetico-deductive reasoning model, led instructional sessions, and evaluated peer pre- and post-experiment reports. These hands-on tasks enabled direct teaching practice and reflective learning.

The second source of self-efficacy, vicarious experiences, refers to observing and modeling successful individuals. To incorporate this source, the instructional design ensured that each PST could observe and learn from their peers—other PSTs participating in the study—during their teaching activities. Additionally, PSTs were allowed to apply insights from these observations in their own two planned teaching activities. Furthermore, these participants had previously completed the Science Teaching Laboratory Practices I course, in which they actively participated in training sessions led by the instructor on guided inquiry-based instruction, allowing them to observe expert-led instruction before implementing it themselves.

Another source of self-efficacy, verbal persuasion, was embedded through structured feedback. PSTs received formative and summative feedback from both peers and the instructor, linking performance appraisal directly to their evolving teaching identity and self-efficacy. Feedback was not only evaluative but also reflective, supporting deeper pedagogical growth.

The final source of self-efficacy, physiological and affective states, was not explicitly addressed in the instructional design; however, the instructor's supportive and constructive demeanor was intended to enhance participants' emotional states and subsequent self-efficacy development.

As illustrated in Fig. 1, the course activities were systematically aligned with Bandura's four sources of self-efficacy. The dual-role structure enabled PSTs to internalize inquiry-based instructional strategies through active engagement in both teaching and observation, enhancing the authenticity and relevance of their learning experience.

The intervention was implemented over 14 weeks, beginning with a focus group interview to assess participants' initial beliefs and expectations, and with the administration of the Group Embedded Figures Test (GEFT) to identify cognitive styles. Each PST assumed the teacher role twice, responsible for designing and facilitating inquiry-based instruction using the hypothetico-deductive reasoning cycle (Lawson, 1995), which included planning lesson content, guiding peers, and evaluating outcomes. Following each session, PSTs completed semi-structured interviews and written self-critiques to document changes in their STSEB.

In their student role, PSTs participated in problem-solving tasks through the same inquiry framework, conducting experiments, submitting pre- and post-experiment reports, and receiving peer feedback. This dual-role model provided an authentic and cyclical teaching and learning experience. Throughout the intervention, the course instructor, also a researcher, ensured fidelity to the instructional model while providing formative support, maintaining an emotionally safe environment that fostered risk-taking and professional growth.

An overview of the data-collection timeline and the tools used throughout the intervention is presented in Fig. 2.

Fig. 2 presents the timeline of data collection across the 14-week intervention. It includes administering the GEFT and the focus group interview in Week 1, followed by semi-structured interviews and self-critiques conducted after each PST's teaching session. Data collection was continuous and staggered, as participants took on the teaching role at different weeks.

3.5. Data analysis

This study utilized qualitative descriptive analysis, defined as the systematic organization of textual data around pre-determined themes (Miles et al., 2014). An analytical framework grounded in components of STSEB from the literature (Enochs & Riggs, 1990) guided the data analysis. Themes, categories, and subcategories aligned with this framework are illustrated in Fig. 3.

All focus group interviews, semi-structured interviews, and self-critique papers were fully transcribed by the researchers. The coding process incorporated both inductive and deductive approaches, consistent with the study's qualitative nature. The coding process began inductively, with open codes generated from participants' statements. These initial codes were then compared and collapsed into the pre-established, theory-driven categories and subcategories derived from Bandura's (1997) self-efficacy framework and the STSEB dimensions (Enochs & Riggs, 1990). Each researcher independently performed open coding on each data set (focus group interviews, semi-structured interviews, and self-critique papers), followed by an analysis of the codes in relation to pre-determined themes and subcategories (Fig. 3). No new

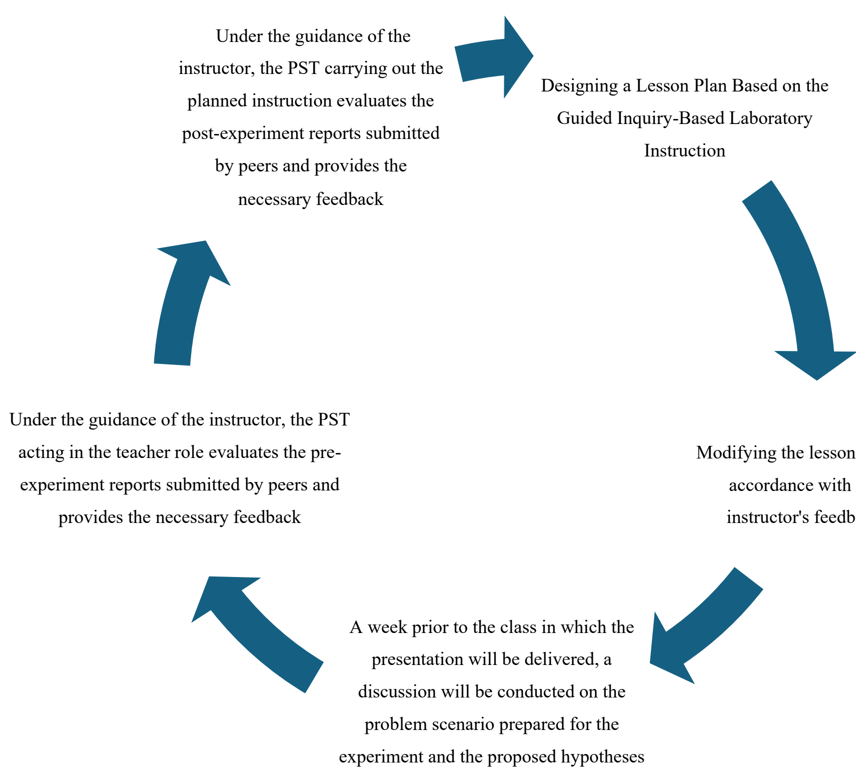

Fig. 1. Science teaching laboratory cycle based on the guided inquiry-based laboratory instruction.

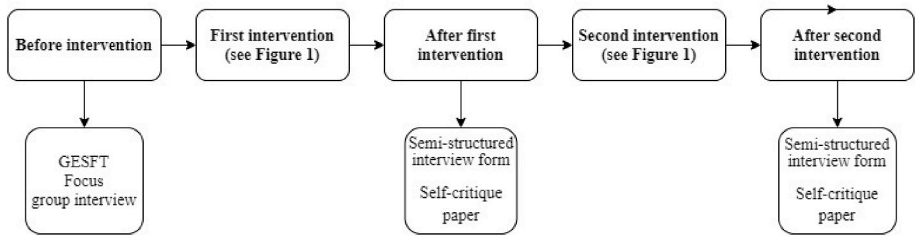

Fig. 2. The data collection timeline and tools used throughout the intervention.

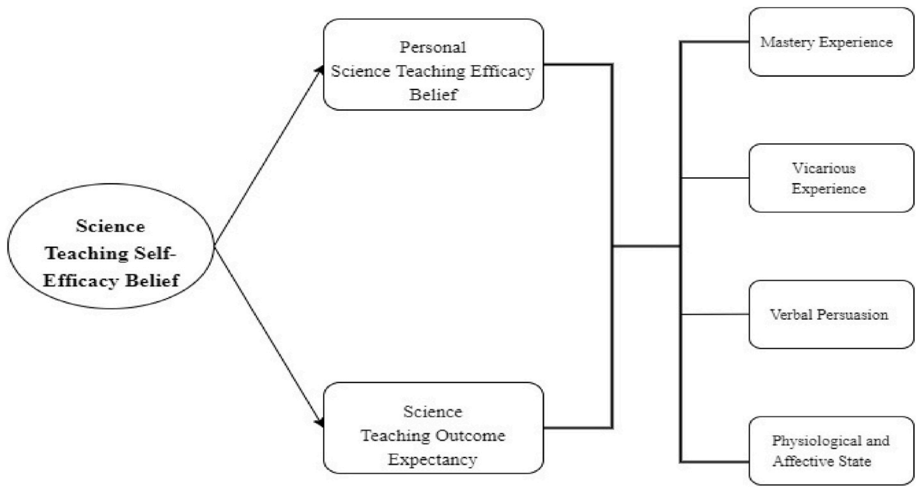

Fig. 3. Categories and sub-categories related to science teaching self-efficacy belief.

themes or subcategories were introduced; instead, the analysis adhered to the existing theoretical framework. To enhance transparency and illustrate the hierarchical structure of the analysis, Table 2 presents the final coding framework, including themes, categories, and representative statements.

As shown in Table 2, the final coding structure reflected Bandura's (1997) four sources of self-efficacy. Each theme encompassed categories that captured the contextual manifestations of mastery, vicarious, verbal, and affective experiences reported by the participants.

Data organization and coding were performed manually using Microsoft Word and Excel, without the aid of qualitative analysis software. Inter-coder reliability was established through a consensus-based approach rather than a statistical measurement. Two researchers independently coded each transcript, discussed discrepancies, and reached agreement through iterative comparison until full consensus was achieved. Discrepancies in code–category alignment were resolved to achieve 100% agreement among researchers, culminating in a final code list. Instead of calculating a statistical reliability coefficient, which is often less meaningful in theory-driven qualitative coding, a consensus-based approach was employed (Miles et al., 2014). Discrepancies were resolved through iterative discussion until agreement was reached, with interpretive coherence prioritized over numerical agreement. This method is consistent with qualitative research standards that emphasize credibility and analytic transparency rather than statistical generalizability. To enhance credibility, data triangulation was employed by analyzing three different data sources (Patton, 2002). Codes derived from each source were systematically cross-checked, and any convergences or discrepancies were discussed to strengthen the findings. Participants' quotations supported the results, thereby increasing the trustworthiness of the analysis (Merriam & Tisdell, 2016). Examples of participant-derived codes organized under themes are presented in Table 4. The study took place over a 14-week GILTLab intervention, with data collected at three intervals: prior to, during the mid-process, and after the intervention. The dataset included 14 pages of focus group transcripts, 42 pages of pre-interview forms, 53 pages of post-interview forms (from the first and second implementations), and 14 and 13 pages of self-critique papers across the two implementations. To ensure confidentiality, participants were anonymized and assigned codes. Throughout the data collection process, the researcher maintained a non-directive stance. Coding decisions were reported transparently, and findings were substantiated with evidence from multiple data sources. These procedures align with strategies recommended by Merriam and Tisdell (2016) to ensure validity and reliability in qualitative data analysis.

Table 2
Coding structure and representative statements.

Theme	Category	Representative Statements
Mastery Experience	Lesson preparation, implementation and reflection	"I enjoyed taking on the role of teacher during my presentation. If I continue working hard, I will become a productive and effective teacher, successfully teaching science." (S2)
Vicarious Experience	Peers/instructor observation and modeling	"We watch how our classmates teach and realize what we should and should not do. This serves as a guide for me, and I use it to compare myself with them." (S5)
Verbal Persuasion	Feedback from peers/ instructor	"Feedback from my classmates makes me feel more comfortable" (S1)
Physiological & Affective States	Emotional and motivational changes	"At first, I was anxious, but I overcame my fear of not being able to communicate with students through this experience." (S4)

Table 3
Alignment of cognitive styles with the four sources of self-efficacy.

Cognitive Style	Mastery Experiences	Vicarious Experiences	Verbal Persuasion	Physiological and Emotional States
Field-independent (S1, S3)	The most dominant and influential source, derived from independent teaching practice and reflection	Limited effect: Peer modeling observed but not central to efficacy development.	Received as confirmation rather than motivation; secondary influence reinforcing mastery outcomes.	Emotional regulation achieved through self-reflection and analytical evaluation rather than external support; emotional states had a limited but stabilizing influence on self-efficacy.
Field-dependent (S2, S4, S5, S6)	Strong but shared with social sources	Highly influenced by peer success and modeling; social observation was a key source of self-efficacy.	Instructor and peer encouragement strongly reinforced self-efficacy.	Emotional and social support from peers and the instructor played a major role in managing anxiety and maintaining confidence; emotional states were strongly linked to self-efficacy fluctuations

3.6. Ethical considerations

This study was approved by the Human Research Ethics Committee (Scientific Research and Publication Ethics Committee for Social and Humanities Sciences), with official authorization granted on February 11, 2021 (Document No: E−57363641-200-23426). Before implementation, all participants were fully informed about the study's purpose and process, and written consent was obtained from each participant. To ensure confidentiality, participants' names were anonymized through coded identifiers used during data coding and reporting.

4. Findings

This section presents the development of PSTs' self-efficacy beliefs regarding science teaching, based on qualitative data. The findings are structured into two phases: first, the within-case analyses, in which each PST's development is examined in its own context; and second, the cross-case analysis, in which similarities and differences across cases are evaluated based on cognitive styles. The analysis was grounded in Bandura's (1997) self-efficacy theory, particularly the four primary sources: mastery experience, vicarious experience, verbal persuasion, and physiological and affective states. The data were holistically analyzed through focus group interviews, interview guides, and self-critique papers.

4.1. Within-case analysis

This section details changes in PSTs' science-teaching self-efficacy beliefs. The development process for the science teaching self-efficacy (STSE) and outcome expectancy (OE) components was analyzed through focus group interviews and reflections following the first and second implementations, guided by Bandura's sources of self-efficacy. Each individual's development was examined within their specific context.

4.1.1. Case S1 (Field-independent)

4.1.1.1. Initial self-efficacy beliefs. During the focus group interview, S1 characterized her science teaching self-efficacy as moderate. She identified empathy as a personal strength that facilitates understanding students and addressing their needs.

4.1.1.2. Personal science teaching self-efficacy (PSTSE). Following the first implementation, S1 reported increased confidence in her content knowledge and teaching experience. She stated, "My strength is my content knowledge" (self-critique paper) and indicated greater comfort in the teaching role compared to the initial stage of the process.

After the second implementation, S1 reported continued growth in confidence as she gained further teaching experience and learned to regulate her initial excitement. She noted, "I think my self-confidence increases every time I teach" (interview forms).

4.1.1.3. Science teaching outcome expectancy (OE). Regarding outcome expectancy, S1 reported increased confidence in her ability to support students' science learning across both implementations. She attributed this development to peer feedback, explaining, "My friends wrote that they understood better during my lesson. When they said that, I thought I must be able to explain well, and I believe it will be the same with my students" (interview forms).

4.1.2. Case S2 (Field-dependent)

4.1.2.1. Initial self-efficacy beliefs. During the focus group interview, S2 reported feelings of inadequacy in science teaching, attributing these to limited methodological knowledge and insufficient experience in lesson planning. She stated, "I have so many shortcomings … I am struggling, but I am trying to pull myself together" (focus group interview).

4.1.2.2. Personal science teaching self-efficacy (PSTSE). Following the first implementation, S2 reported increased confidence after assuming the teacher role. She explained, "My belief changed in a positive direction. I really enjoyed stepping into the teacher role. I believe that if I try, I can teach science effectively" (interview forms).

After the second implementation, S2 indicated further growth in confidence. She emphasized that advance lesson preparation and conducting research enhanced her sense of capability: "My self-efficacy increased. I became more investigative, more questioning, and as a result, I prepared a better lesson plan" (interview forms).

4.1.2.3. Science teaching outcome expectancy (OE). Regarding outcome expectancy (OE), S2 reported changes following the first implementation, attributing her development to feedback received during the process. She noted, "Thanks to the feedback, I will be better prepared for the next lesson, and the conclusions I have drawn will help me move one step further" (self-critique paper).

After the second implementation, S2 reported increased attentiveness to fostering meaningful learning through questioning and hypothesis-based discussions. She stated, "Thanks to this cycle, I managed the process better … I can ask thought-provoking questions during the lesson" (self-critique paper).

4.1.3. Case S3 (Field-independent)

4.1.3.1. Initial self-efficacy beliefs. During the focus group interview, S3 reported a lack of competence in planning science lessons and designing experiments. He expressed uncertainty regarding lesson plan preparation and described apprehension about making mistakes during laboratory activities: "I don't exactly know where to start when preparing a lesson plan. I am afraid of making mistakes during the experiment part" (focus group interview).

4.1.3.2. Personal science teaching self-efficacy (PSTSE). Following the first implementation, S3 reported increased confidence despite initial struggles in assuming the teacher role. He reflected on the experience as follows: "I realized I had done some things inadequately while preparing

Table 4
Sources of self-efficacy and sample participant statements.

Source of Self-Efficacy	Cognitive Style	Intervention	Type of Efficacy	Sample Quotations
Mastery Experience	FDI	1	PSTSE	I can feel happy when I accomplish something myself, and at those moments, I can boost my self-confidence more. (S3, interview forms)
Mastery Experience	FDI	2	OE	My confidence increased because my peers started asking me more questions, and I was able to provide them with answers. To achieve this, I prepared well for the questions I needed to ask in class and the pre-experiment reports. (S3, interview forms)
Mastery Experience	FDI	1	OE	I have communication difficulties. I was not very active in the intervention, and I got a bit nervous. If I cannot improve my communication skills, I will be unable to assess whether my students understand the topic. However, communicating more during the implementation made me feel more comfortable and confident. (S1, self-critique paper and interview forms)
Verbal Persuasion	FDI	2	PSTSE	Feedback from my classmates makes me feel more comfortable. (S1, interview forms)
Verbal Persuasion	FDI	2	OE	I reviewed my peers' post-experiment reports. They wrote that they understood the lesson better during my instruction. When my peers write that, I can explain things effectively. (S1, interview forms)
Mastery Experience	FD	1	PSTSE	I enjoyed taking on the role of teacher during my presentation. If I continue working hard, I will become a productive and effective teacher, successfully teaching science. (S2, interview forms)
Vicarious Experience	FD	1	PSTSE	I will be one step ahead thanks to what I learned from my peers' presentations. (S2, self-critique paper)
Verbal Persuasion	FD	1	PSTSE	The feedback from my classmates will help me be more prepared for the next lesson. (S2, interview forms)
Mastery Experience	FD	1	OE	Yes, my belief has changed. The presentation had a significant impact on me by the end of the intervention because I was able to communicate effectively. Creating a lesson plan was a meaningful experience, just like delivering my first presentation. (S4, interview forms, self-critique paper)
Physiological and Affective State	FD	1	PSTSE	You are always trying to engage with us, and I like that, professor. Since you show interest in us, I am more motivated to participate. (S4, interview forms)
Vicarious Experience	FD	2	OE	I tell myself that I will do the same as my peers or think about how I can improve. Sometimes, I imitate my friends; sometimes, I imitate you. By imitating, I can develop myself. (S4, interview forms)
Vicarious Experience	FD	1	PSTSE	We watch how our classmates teach and realize what we should and should not do. This serves as a guide for me, and I use it to compare myself with them. I liked how S3 explained topics through discussion, how S2 encouraged us to think critically, and how S6 surprised us with a different perspective. Watching my peers, I want to incorporate their strengths into my teaching. (S5, interview forms, self-critique paper)
Vicarious Experience	FD	1	PSTSE	When I watched my peers' presentations, I admired how S3 examined experiments, how S2 communicated, and how S5 analyzed hypotheses. I want to adapt these skills to my teaching because the more effectively I

(continued on next page)

Table 4 (*continued*)

Source of Self-Efficacy	Cognitive Style	Intervention	Type of Efficacy	Sample Quotations
				implement the inquiry cycle, the more successful I will be. (S6, interview forms)

for the lesson, but this was a good experience for me. My belief in my ability to teach science increased … actually, nothing is impossible … I think I become happy when I accomplish something, and that is when my confidence grows" (interview forms).

After the second implementation, S3 referred to further changes in confidence, particularly emphasizing preparation and systematic planning. He stated, "I have overcome my fears … now I know that if I were to prepare a lesson plan on any topic, it would not be done in a couple of days—it would take at least a week, and I can plan it systematically" (interview forms).

4.1.3.3. Science teaching outcome expectancy (OE). Regarding outcome expectancy (OE), S3 reported increased attentiveness to student engagement across the two implementations. After the first implementation, he noted the importance of encouraging active student participation in discussions. Following the second implementation, he emphasized the use of questioning strategies, stating, "I realized that if I ask questions while explaining a topic to my own students, I can get them more involved in the lesson" (interview forms).

4.1.4. Case S4 (Field-dependent)

4.1.4.1. Initial self-efficacy beliefs. During the focus group interview, S4 reported low confidence in her teaching ability despite perceiving her content knowledge as strong. She stated, "Right now, I absolutely do not believe in myself. I have the knowledge, but I cannot transfer it to students" (focus group interview).

4.1.4.2. Personal science teaching self-efficacy (PSTSE). Following the first implementation, S4 reported increased confidence, particularly regarding hypothesis formulation, experiment design, and communication. She noted, "I think my hypotheses and experiments are solid. I can approach variables from different perspectives" (self-critique paper). She also highlighted the influence of peer collaboration and instructor feedback, stating, "When my peers make mistakes, I learn from them … You always show interest, and that motivates me to do my best" (interview forms).

After the second implementation, S4 reported further increases in confidence, emphasizing the importance of preparation and self-evaluation. She stated, "I trust myself now … I prepare really well for my presentations and constantly evaluate myself" (interview forms). She also described learning through observation and imitation, explaining, "I plan the same way as my peers or sometimes imitate them and my instructor to improve myself" (interview forms).

4.1.4.3. Science teaching outcome expectancy (OE). Regarding outcome expectancy (OE), S4 reported increased confidence in facilitating student learning. After the first implementation, she described overcoming communication-related anxiety: "I overcame my fear of not being able to communicate … this presentation gave me confidence" (interview forms). Following the second implementation, she continued to reference improved communication and explanation skills, stating, "I overcame my fear of not being able to communicate with students … now I know how to explain things better" (interview forms; self-critique paper).

4.1.5. Case S5 (Field-dependent)

4.1.5.1. Initial self-efficacy beliefs. During the focus group interview, S5 reported difficulties in communication and adapting to new environments, while expressing confidence in subject matter knowledge. S5 stated, "When I enter a new environment, I cannot immediately adapt. My communication is a bit weak, but I trust my content knowledge" (focus group interview).

4.1.5.2. Personal science teaching self-efficacy (PSTSE). Following the first implementation, S5 reported increased confidence and emphasized the influence of observing peers' teaching practices. S5 explained, "Watching how my peers teach helps me see what I should or shouldn't do. I plan to adopt the positive aspects of their approaches" (interview forms; self-critique paper).

After the second implementation, S5 reported increased confidence after independently designing and delivering a lesson. S5 stated, "I truly felt like a teacher—I designed the scenario, conducted experiments, and taught the subject" (interview forms). Peer observation and instructor feedback were also identified as influential, as reflected in the statement, "Seeing my peers' lessons made me think, 'I can do this too.' Feedback, whether positive or negative, helped me improve" (interview forms; self-critique paper).

4.1.5.3. Science teaching outcome expectancy (OE). Regarding outcome expectancy (OE), S5 reported increased attentiveness to the role of feedback and reflection in improving teaching practices following the first implementation. S5 noted, "With the feedback I received from my instructor and by observing my peers, I noticed my mistakes and planned how to correct them" (self-critique paper).

After the second implementation, S5 highlighted the importance of active student engagement for effective learning, stating, "If students are active rather than passive, I believe they understand the subject better" (interview forms).

4.1.6. Case S6 (Field-dependent)

4.1.6.1. Initial self-efficacy beliefs. During the focus group interview, S6 reported feeling inadequate in science content knowledge, particularly in chemistry, while expressing greater confidence in physics and biology. She also reported confidence in her communication and classroom management skills.

4.1.6.2. Personal science teaching self-efficacy (PSTSE). Following the first implementation, S6 reported increased confidence after taking full responsibility for teaching. She stated, "For the first time, I had full control of the lesson, and that increased my self-confidence" (interview forms). She also emphasized the influence of peer observation and instructor feedback in lesson preparation: "Watching my peers and listening to your feedback helped me prepare better lessons" (interview forms).

After the second implementation, S6 reported further increases in confidence, particularly in classroom management and engagement with scientific reasoning. She noted, "This technique taught me hypothetical thinking, and my classroom management has improved" (interview forms). She also emphasized the value of feedback in refining lesson design, stating, "Feedback matters—it helps identify and correct mistakes from an external perspective" (interview forms).

4.1.6.3. Science teaching outcome expectancy (OE). Regarding outcome expectancy (OE), S6 reported increased awareness of facilitating student learning after the first implementation, explaining, "I think my belief increased because my lesson was followed well and there was active participation" (interview forms).

Following the second implementation, S6 reported greater confidence in supporting students' understanding of complex topics. She stated, "I taught two difficult topics, and I think both were understood by the class. That is why my belief in their success increased" (interview forms).

4.2. Cross-case comparison

In this section, the development processes of PSTs' self-efficacy beliefs (both PSTSE and OE) are evaluated using Yin's (2014) cross-case analysis. The analysis is grounded in Bandura's (1997) self-efficacy theory, which identifies four key sources of self-efficacy—mastery experience, vicarious experience, verbal persuasion, and physiological and affective states—and interprets them within the context of cognitive styles (field-dependent and field-independent).

In the following subsections, findings related to personal science teaching self-efficacy (PSTSE)—reflecting participants' confidence in their own teaching ability—are presented separately from those related to science teaching outcome expectancy (STOE), which represent beliefs about the influence of teaching on students' learning outcomes. This distinction guided both the within-case and cross-case interpretations.

4.2.1. Comparison of personal science teaching self-efficacy (PSTSE) component

Regarding the PSTSE component, field-dependent participants (S2, S4, S5, S6) primarily benefited from direct teaching experiences. Peer observation and instructor feedback were also frequently identified as significant factors in enhancing their confidence. Initially, these participants reported low confidence, communication anxiety, and hesitation during teaching. However, repeated teaching opportunities and feedback over time contributed to increased confidence. In contrast, field-independent participants (S1, S3) identified independent enactment of the teaching role as the primary factor in developing self-efficacy. They emphasized lesson preparation, experimentation, and learning from personal mistakes as central to their increasing confidence. For example, one field-dependent participant stated, "At the beginning, I hesitated a lot during teaching, but observing my peers and hearing the instructor's feedback helped me improve step by step" (S2, interview forms). In contrast, a field-independent participant remarked, "Preparing and conducting the experiment myself gave me real confidence" (S3, interview forms).

4.2.2. Comparison of outcome expectancy (OE) component

Regarding the outcome expectancy (OE) component, participants from both cognitive style groups reported increased confidence in their ability to influence students' science learning throughout the intervention. Field-dependent participants frequently cited repeated teaching implementations, peer modeling, and instructor feedback as key factors shaping these beliefs. In contrast, field-independent participants emphasized personal teaching experiences as central to their OE development. They reported increased attentiveness to lesson planning, anticipation of student misconceptions, and more deliberate structuring of classroom discussions. For example, one field-dependent participant stated, "When I create a positive atmosphere, students respond better. Their understanding gives me confidence in my teaching." (S6, interview forms). Similarly, a field-independent participant explained, "While planning the lessons, I became more conscious of how students would learn each step of the experiment. When they conduct it themselves, I can clearly see they truly understand the concept." (S1, interview forms).

Across cases, participants described positive shifts in both preservice teacher science self-efficacy (PSTSE) and outcome expectancy (OE) following the teaching practices. Mastery experiences were frequently referenced, particularly by field-independent participants. Field-dependent participants also highlighted peer observation and instructor feedback as influential in shaping their confidence.

Table 3 summarizes cross-case patterns, illustrating how field-dependent and field-independent participants emphasized different aspects of mastery experiences, peer observation, feedback, and emotional influences.

As noted by Yin (2014), cross-case analysis in multiple-case study designs reveals broader patterns that transcend individual differences. Fig. 4 summarizes the frequency of self-efficacy sources related to PSTSE and OE components following the implementation of the GILTLab. Fig. 4 summarizes the frequency of self-efficacy sources related to PSTSE and OE components following the implementation of the GILTLab.

The data reaffirm findings from case analyses, indicating that mastery experience is the most cited and impactful source among participants. For field-independent participants, mastery experience primarily drove their development across both components, while field-dependent participants also benefited significantly from peer observations and feedback. No significant changes occurred in the dominant self-efficacy sources between the first and second implementations for either cognitive style group, maintaining a consistent pattern among participants. Illustrative participant statements supporting these conclusions are detailed in Table 4, which presents quotations coded according to the study's thematic framework, aligning with the relevant self-efficacy sources (e.g., mastery experience) and dimensions (PSTSE or OE).

5. Discussion

This study investigated the changes in STSEB among PSTs with differing cognitive styles following the implementation of the GILTLab. The findings offer valuable implications regarding the impact of this intervention on the development of STSEB across diverse cognitive styles.

5.1. General impact of GILTLab on self-efficacy beliefs

The results indicate that the GILTLab intervention enhanced both dimensions of self-efficacy beliefs: PSTSE and OE. These findings are consistent with previous research aimed at enhancing pre-service science teachers' STSEB through inquiry-based instructional methods in science laboratory courses (Akyol & Taş, 2024; Kyriazis et al., 2025; Kıran, 2022). Furthermore, the findings support previous studies that demonstrate the effectiveness of instructional designs incorporating self-efficacy sources in fostering the development of teaching-related self-efficacy beliefs in pre-service teachers (Atasoy & Cakıroglu, 2018; Lotter et al., 2018). In summary, these findings further support the potential effectiveness of inquiry-based teaching methods and instructional designs tailored to the nature of self-efficacy beliefs in enhancing STSEB among pre-service teachers.

5.2. Sources of self-efficacy development

An analysis of the sources contributing to self-efficacy beliefs in the PSTSE and OE dimensions revealed that mastery experiences were the most influential source for both. In the PSTSE dimension, vicarious experiences, verbal persuasion, and affective states followed mastery experiences in order of importance. A similar ranking was observed for OE, though the influence of affective states was more limited. These findings indicate that direct engagement in guided inquiry activities provided meaningful experiences that effectively enhanced pre-service teachers' self-efficacy beliefs. The central role of mastery experiences in self-efficacy development aligns with Bandura's (1977) theory and previous research (Kleppang & Steigen, 2023; Nordin et al., 2018). This further supports studies emphasizing the importance of experience-based learning in fostering STSEB (Akyol & Taş, 2024; Beck & Blumer, 2021; Kıran, 2022; Lotter et al., 2018). Palmer (2006) proposed that cognitive content mastery (understanding new content) and cognitive pedagogical mastery (learning new ways to teach content) are two key mastery experiences influencing STSEB. The findings suggest

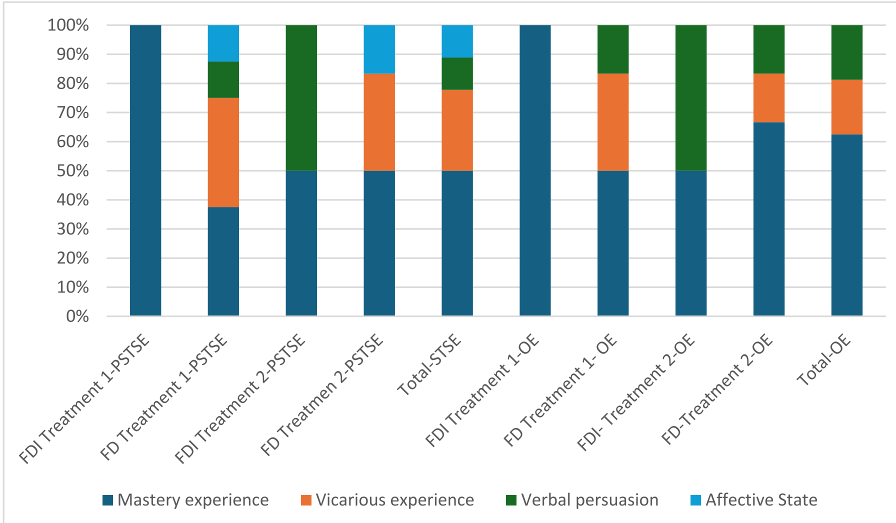

Fig. 4. Utilization of self-efficacy sources by PSTs with different cognitive styles.

that GILTLab effectively supported both components, thereby distinguishing itself from prior research. Studies in the literature have demonstrated the positive impact of both components on STSEB (Zundans-Fraser & Lancaster, 2012). During GILTLab, participants engaged in mastery experiences in understanding scientific content and developing instructional strategies. This dual engagement distinguishes the study from other research, as science content courses and science methods courses typically emphasize only one of these components. Research on science content courses has focused more on cognitive content mastery, whereas science methods courses emphasize cognitive pedagogical mastery. In the present study, PSTs spent 12 weeks in the student role, extensively utilizing cognitive content mastery. During the two-week period in which they assumed the teacher role, they engaged in various responsibilities, including lesson planning, implementing guided inquiry activities, and providing feedback on experiment reports. This phase enabled them to develop both cognitive content mastery and cognitive pedagogical mastery, making this study unique in its ability to integrate both dimensions of mastery experiences within a single instructional design.

5.3. Differences based on cognitive styles

When comparing PSTs with different cognitive styles, mastery experiences were found to be the most influential source of PSTSE and OE for field-independent PSTs. However, for field-dependent PSTs, self-efficacy beliefs were shaped not only by mastery experiences but also by vicarious experiences, verbal persuasion, and physiological and affective states in a more balanced manner. These findings can be further interpreted through the lens of cognitive style theory. Field-independent PSTs, who process information analytically and rely on internal frames of reference, are more likely to derive self-efficacy primarily from mastery experiences. In contrast, field-dependent PSTs, characterized by stronger social orientation and reliance on external cues, tend to draw on vicarious experiences, verbal persuasion, and affective feedback (Naraghipour & Baghestani, 2018; Tinajero & Paramo, 1998; Witkin & Goodenough, 1976). These differences illustrate how cognitive style modulates the relative activation of Bandura's (1997) four sources of efficacy, shaping distinct self-efficacy development pathways within inquiry-based instruction.

Furthermore, the comparative analysis revealed that for FI PSTs, mastery experiences were the dominant source influencing both personal science teaching self-efficacy (PSTSE) and outcome expectancy (OE). For field-dependent PSTs, however, self-efficacy beliefs were more evenly shaped by mastery, vicarious, persuasive, and affective experiences. These findings are consistent with prior research suggesting that field-dependent individuals benefit more from social and emotional support than their FI counterparts (Naraghipour & Baghestani, 2018; Saracho, 1997; Witkin & Goodenough, 1976).

Although mastery experiences are well established as the strongest determinant of self-efficacy (Kleppang & Steigen, 2023; Nordin et al., 2018), positive experiences alone do not necessarily lead to increased efficacy. Learners must cognitively interpret and internalize these experiences in relation to personal and contextual factors (Britner & Pajares, 2006). From this perspective, cognitive style operates as a mediating individual difference that shapes how individuals process and transform experience into self-efficacy beliefs.

From a pedagogical standpoint, these results suggest that science teacher education programs should deliberately differentiate feedback, grouping, and scaffolding strategies according to cognitive style. Field-dependent PSTs may benefit most from structured peer modeling, explicit verbal encouragement, and emotionally supportive environments, while FI PSTs may thrive in autonomy-oriented and self-reflective contexts. Notably, the dual teacher–student role within the GILTLab functioned as a unique scaffolding mechanism, enabling participants to experience both mastery and modeling processes from complementary perspectives. This design feature provided a robust framework for integrating theory and practice in the development of science teaching self-efficacy.

Collectively, the findings indicate that cognitive style influences how pre-service teachers interpret and prioritize various sources of efficacy. Although mastery experiences were central for all participants, field-independent pre-service teachers primarily internalized efficacy through direct task accomplishment, while field-dependent pre-service teachers integrated social and affective cues more prominently. This interpretation builds upon Bandura's (1997) framework by emphasizing the significance of individual cognitive processing differences in shaping the activation of efficacy sources within inquiry-based laboratory settings. Due to the small and context-specific sample, the study's contribution is not statistical generalization but rather a conceptually grounded interpretation through analytic generalization (Yin, 2014). Accordingly, these findings provide direction for future research on the influence of cognitive style on the activation of self-efficacy sources in inquiry-based contexts.

6. Conclusion

This study examined the impact of the GILTLab intervention on PSTs' self-efficacy beliefs in teaching science, with a particular focus on differences across cognitive styles. The findings indicate that participation in GILTLab enhanced self-efficacy beliefs in both PSTSE and OE, confirming the effectiveness of inquiry-based laboratory experiences that are explicitly aligned with the sources of self-efficacy.

A key contribution of this study is the identification of mastery experiences as the most influential source of self-efficacy, while also showing that field-dependent students benefited more strongly from complementary sources such as social modeling, verbal persuasion, and affective states. These findings highlight the importance of designing teacher education programs that combine mastery-based learning opportunities with social and emotional support mechanisms tailored to diverse cognitive styles.

Overall, this research underscores the value of guided inquiry laboratory designs, such as GILTLab, in strengthening PSTs' science-teaching self-efficacy. By integrating opportunities to experience both the student and teacher roles, the intervention provided a unique dual perspective that enriched participants' professional development. The study thus contributes to ongoing efforts to enhance science teacher education by linking inquiry-based practice, cognitive styles, and the sources of self-efficacy.

7. Limitations

Several limitations should be considered when interpreting the findings of this study. First, the research involved only six participants. While participants' dual experience in both student and teacher roles enriched the study, the small sample size limits the generalizability of the findings. The qualitative data collection aimed to explore participants' STSEB; however, diversity in individual characteristics (e.g., gender, academic achievement) may constrain comparative analyses of PSTs with varying cognitive styles. Although participants were from a similar background in the same teacher education program, individual differences could influence self-efficacy development and should be taken into account when interpreting the results.

Second, the dual role of the researcher as both instructor and investigator may have introduced a potential source of bias. Because the researcher also taught the course, the participants' responses may have been influenced by existing student–teacher relationships or perceptions of evaluation. This influence was not directly measured or controlled in the present study, which represents a limitation. Future research could address this issue by employing independent instructors or external observers to minimize potential instructor effects.

Third, a limitation is the lack of a standardized self-efficacy instrument. While reflection-based measures provided rich, context-specific insights, the lack of a standardized tool may compromise the comparability and transferability of findings across contexts. In particular, while the self-critique papers aligned with Bandura's sources of self-efficacy, participants' general cognitive abilities might still have influenced their responses, suggesting that the tool offered valuable insights but did not isolate self-efficacy beliefs from broader cognitive competence.

Fourth, although field-dependent and field-independent cognitive styles are often contrasted, cognitive style exists on a spectrum, and a binary classification may inadequately capture individual differences, warranting cautious interpretation.

Finally, the 14-week GILTLab intervention was implemented within a specific institutional and national context. In Turkey, the Science Teaching Laboratory Practices I and II courses are a standard component of all science teacher education programs, which supports the relevance and transferability of the findings within the national context. However, teacher education programs in other countries may differ in structure, duration, and available resources, which could limit the model's broader international transferability. Nevertheless, the design could be adapted in modular or shorter forms to fit diverse institutional contexts. In addition, participants who had taken the same laboratory course in the previous semester may have influenced the findings. All students who had taken the Science Teaching Laboratory Practices I course voluntarily participated, with only one declining due to transferring to another institution. While prior exposure may have familiarized participants with the instructional approach, during the current study, they assumed the teacher role, preparing lessons and conducting inquiry-based activities—representing a significant experiential shift. Despite this, the voluntary nature of participation and prior familiarity with the instructional setting remain contextual limitations affecting transferability.

8. Recommendations for future research

This study is a qualitative investigation aimed at exploring the development processes of STSEB among PSTs. Future research, employing quantitative or mixed-methods designs with larger, more diverse samples, may facilitate the use of Aptitude-Treatment Interaction (ATI) designs, particularly in relation to cognitive styles, thereby yielding more generalizable insights into self-efficacy development.

The GILTLab implementation involved six participants, with activities conducted individually due to the limited number. Future investigations should consider collaborative group work with a higher number of PSTs. Additionally, studies employing open inquiry rather than guided inquiry could examine how factors such as social modeling, verbal persuasion, and emotional states influence self-efficacy beliefs among PSTs with varied cognitive styles.

Finally, it is recommended that future studies incorporate validated self-efficacy scales alongside qualitative instruments. Doing so may enhance the validity of findings, improve comparability across studies, and support the transferability of results to different instructional contexts.

CRediT authorship contribution statement

Feride Sahin: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Conceptualization. **Fatma Sasmaz Oren:** Writing – original draft, Supervision, Conceptualization.

Declaration of Generative AI and AI-Assisted technologies in the writing process

During the preparation of this work, the authors used [ChatGPT/Consensus] to improve the readability and language of the manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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Data availability

Data will be made available on request.

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