

REVIEW

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Science teacher identity research: a scoping literature review

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Abstract

Science teacher identity significantly influences teacher professional development, practices, and attitudes, which in turn impacts student learning outcomes. With an increased number of studies on science teacher identity over the past two decades, there is a need for a scoping literature review that holistically maps the current state of science teacher identity research and identifies future research directions. This scoping literature review identified 48 empirical articles on science teacher identity, published from 2000 to 2023, in peer-reviewed journals and examined the studies' (a) characteristics; (b) theoretical frameworks on identity; (c) definitions of science teacher identity; and (d) major findings. Specifically, there is a need for precise conceptualizations and definitions of science teacher identity; this clarity will facilitate valid, reliable, and fair instruments to capture the relatively stable facets of science teacher identity at a given moment in a given context in order to longitudinally track science teacher identity development. This scoping review identifies both progress and gaps in the current literature and future directions for synergistic, cross-cultural international research on science teacher identity.

Keywords Science teacher identity, Preservice teacher education, In-service teacher education, Teacher learning and development, Systematic literature review, Scoping literature review

Introduction

Teacher education research has evolved over the years from a focus on curriculum (1920–1950) to training (1960s–1980s) to teacher learning (1980s–2000s) (Cochran-Smith & Fries, 2008). In science education, since the 2000s, there has been increased attention towards the relationship among teacher learning, student learning, and context, including education policies and their roles in teacher learning (Wallace & Loughran, 2012). There is a large body of literature on the development of teacher professional knowledge, particularly science teachers' pedagogical content knowledge (PCK) (Loughran et al., 2012; van Driel et al., 2014). There is also

considerable research on science teachers' understanding of practices and learning to teach (Loughran, 2014; Russell & Martin, 2014), teachers' attitudes and beliefs of science reform practices (Jones & Leagon, 2014), and in-service science teacher professional development programs (Luft & Hewson, 2014).

Within this context of science teacher education research, over the past two decades there has also been increased international interest and subsequent publications in science teacher identity (e.g., Holmegaard & Archer, 2022; Lee, 2007). This global trend resembles that of teacher identity in general, which has been a mainstay in teacher education research since the 1990s (Beauchamp & Thomas, 2009; Bullough, 1997). Apart from other research on teacher learning, science teacher identity research considers teacher learning as a holistic process and outcome. Specifically, by using science teacher identity as a lens, researchers have examined how teachers view themselves, are recognized by others, and how teachers' other identities (e.g., race and gender), personal

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histories, and prior experiences with science and education shape who they are as science teachers (Avraamidou, 2014a, 2016a; Varelas, 2012).

In a literature review of research on science teacher identity, Avraamidou (2014a) identified 29 empirical studies published in leading science education journals as well as in *Journal of Learning Sciences* and *Journal of Teacher Education* from 2001 to 2013. Aside from two studies that focused on science identities of women of color in science, as opposed to identities of science teachers, that were also included in the review, all studies in Avraamidou (2014a) recognized science teacher identity as a valuable lens to frame and examine science teacher learning and development; they also acknowledged that science teacher identity is complex, multidimensional, and comprised of various components that are situated within and shaped by multiple contexts across time and scale.

Avraamidou's (2014a) review offered a foundational overview of science teacher identity research and made notable recommendations for future research. These recommendations include: (a) studying teacher identity as a process, (b) connecting science teacher identity research and reform recommendations, (c) conducting large-scale, longitudinal, and life-history studies, (d) examining science teacher identity enactment in school classrooms, and (e) understanding the role of various contexts on science teachers' identity development. However, by broadening eligibility criteria and searching only in specific journals, Avraamidou (2014a) did not follow systematic literature review conventions, as defined by the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) 2009 (Page et al., 2021). Moreover, Avraamidou (2014a) focused the review in two areas: (1) how science teacher identity was used in science education research and (2) approaches used to support science teacher identity development. Thus, as Avraamidou (2014a) noted, it is "probable that other significant findings of the studies reviewed have not been examined" and that "work that has been published in journals not included in [the] search" were overlooked (p. 151).

Given that it has been ten years since Avraamidou's (2014a) review was published, an updated, systematic literature review on science teacher identity research would help the science education community understand the current state of science teacher identity research and identify gaps and desirable future research directions in this evolving field. In the past several years, several systematic literature reviews have made progress towards this goal while also establishing the growing global significance of science teacher identity. For example, Rushton and Reiss's (2021) systematic review of empirical journal articles, doctoral dissertations, theoretical studies,

conference proceedings, and book chapters published from 2000 to 2019, used a social identity approach (SIA) to examine how identity is used to explore the experiences of middle and high school science teachers. Using the SIA lens, they noted the important role of shared identity or group membership in developing one's sense of self or individual identity as science teachers, as well as social context. Due to their focus, research that attends to science teacher identity of elementary teachers was excluded as well as a synthesis of findings using other lenses. Consistent with Avraamidou (2014a), Rushton and Reiss (2021) note the range of theoretical and conceptual frameworks in exploring science teacher identity development, though they leave more to be unpacked in terms of how these various frameworks relate and diverge from each other, along with their affordances and constraints.

Feser and Haak (2023) conducted a systematic review of 24 reviews published from 2004 to 2021 (i.e., a meta-review of research on teacher identity), that attended to literature published before 2020 with a focus on identifying significant features of teacher identity, which span across theoretical frameworks of personal, social, collective, positional, and narrative identity, and consider identity change and maintenance. Some teacher identity features were more prevalent in teachers of science and related subjects, such as nursing and mathematics, than other features. Notably, this review's results strongly indicated that the identity of science teachers significantly differs from the identity of other subject area teachers or generalist teachers and that "science teachers do not constitute a homogenous group in terms of their teacher identity" (Feser & Haak, 2023, p. 310). Namely, science teacher identity differs depending on whether one is a beginning or experienced science teacher, or teaches in primary, secondary, or higher education. Altogether, the Feser and Haak (2023) review underscores the importance of further research into science teacher identity, given its unique, complex nature, the potential for identifying new features of science teacher identity in future studies, and further exploring how it develops and differs depending on science teaching experience and the grade level(s) taught.

Another recent review of research methods and methodologies of 198 empirical peer-reviewed journal articles, published between 1998 and 2018, was conducted by Danielsson and colleagues (2023). This review, which focused on *science identity* among *science learners*, not *science teacher identity* among *science teachers*, found that micro-studies within an interpretative tradition were most prevalent, although psychological macro-studies and sociological macro-studies were, albeit comparatively less common approaches.

Despite the rapid growth of science identity research over the last 20 years, Danielsson et al. (2023) argued for more precision in defining and conceptualizing science identity and for more interaction across studies and approaches. As this review focused on science identities of science learners, there is a need to take stock of the methodological approaches used in science teacher identity research and the variation and clarity with which science teacher identity is defined and conceptualized.

Accordingly, our scoping review builds upon and extends this foundation of the above recent reviews to map out the trends in science teacher identity research and to gauge the field holistically, to inform future research and practice areas. Apart from these other reviews, our review centers solely on science teacher identity of elementary through high school teachers, across career stages, and includes empirical peer-reviewed journal articles published from 2000 to 2023, which captures science teacher identity research published in the past 5 years, that have not been included in previous reviews. Specifically, the following research questions guided our scoping review:

1. What were the characteristics of empirical science teacher identity research studies?
2. What theoretical frameworks of identity were utilized in empirical science teacher identity research studies?
3. How was science teacher identity defined in empirical science teacher identity research studies?
4. What were the major findings in empirical science teacher identity research studies?

Thus, our review examines characteristics of science teacher identity studies, which include the distribution of publications from 2000 to 2023, methodological approaches used, country contexts and classification of study areas as rural, urban, or suburban, and science teacher participants' racial/gender identities, science teaching subjects, and career stages. Since science teacher identity is examined from multiple theoretical perspectives (Rushton & Reiss, 2021), it is important to unpack the theoretical frameworks and definitions of science teacher identity used in these studies, to explore any similarities and differences, along with strengths and limitations of these lenses. Such clarity will assist in the development of valid, reliable, and fair instruments for use in large-scale, longitudinal quantitative and mixed-methods studies that have been recommended (Avraamidou, 2014a; Rushton & Reiss, 2021). We also document major findings obtained in these studies according to the type of research questions asked. Our scoping literature

review's focus therefore differs from and extends beyond those from previous literature reviews.

Answers to these research questions can provide an overall picture of science teacher identity research by identifying major components of science teacher identity; factors affecting its formation and development; and the extent, scope, and nature of theories and findings on science teacher identity. Teacher professional identity plays a fundamental role in quality of teaching, professional development, and a successful long-term career in the teaching profession (Suarez & McGrath, 2022). Given global efforts to bolster teacher recruitment and retention, particularly in science fields (Rushton & Reiss, 2021), and the unique nature of science teacher identity as compared with teacher identity in general or that of other subjects (Feser & Haak, 2023), through studying science teacher identity, we can better train and support science teachers for long-term retention. Moreover, since science teacher identity influences teacher practices and attitudes, which in turn impact student learning outcomes, studying science teacher identity can better inform science teacher education policies and practices.

Conceptual framework

Our scoping literature review is informed by the Teacher Professional Identity (TPI) development and outcome model, represented in Fig. 1; this conceptual framework is developed from international reviews of the literature and secondary Organisation for Economic Co-operation and Development (OECD) data from around the world, which makes it useful for understanding TPI from a global perspective (Suarez & McGrath, 2022). Different from a theoretical framework, a conceptual framework is a "description of the way a researcher understands the factors and/or variables that are involved in the study and their relationships to one another" (Luft et al., 2022, p. 6). As such, this TPI conceptual framework allowed us to articulate concepts and clarify connections among the concepts that are central to our scoping review; it served as a starting point and guide as we developed our research questions, literature search, coding scheme, and understanding of science teacher identity conceptualizations, definitions, and research findings.

This conceptual framework demonstrates the dynamic, evolving, and constructed nature of TPI formation and development. The model indicates that various institutional and sociocultural contexts (e.g., classroom, science department, school, educational systems, and policies); interpersonal relationships, group affinities, and colleague collaboration influence teacher identity (Davey, 2013); and that teacher identity influences teacher attitudes, behaviors, and student learning outcomes (Suarez & McGrath, 2022).

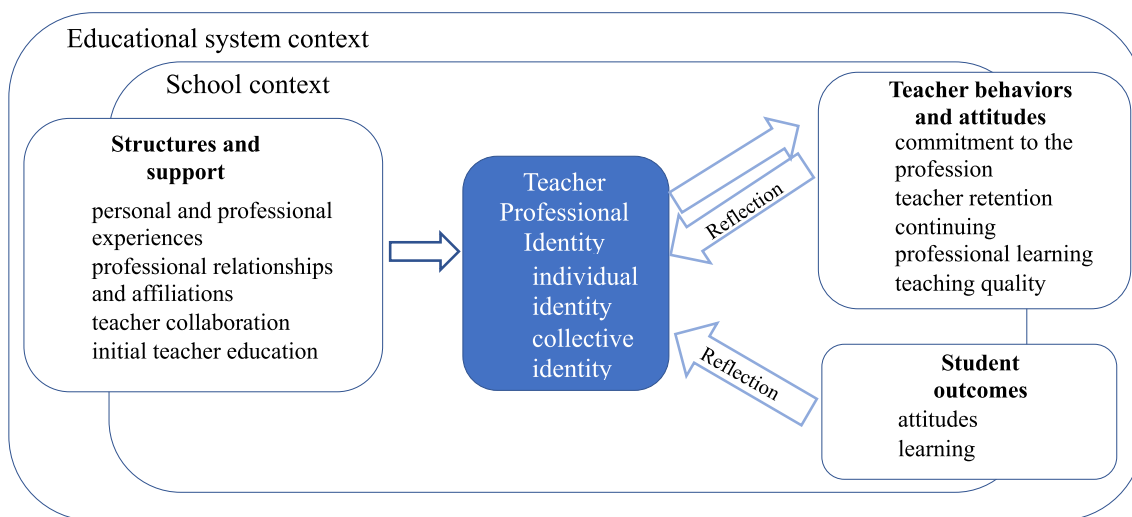


Fig. 1 Teacher professional identity (TPI) development and outcome model (Suarez & McGrath, 2022)

Therefore, teachers’ personal and professional experiences are mediated by contexts, including the level of support they receive, which informs how they view their roles, and their commitment to the profession, and continuous improvement (Rodrigues & Mogarro, 2019). These actions and student outcomes provoke personal and collective teacher reflection, which allows teachers to better understand themselves and their practices, which spurs reconfiguration of their professional identities (Day et al., 2006). It is important to note that reflection is a recursive process, and the relationships among model elements are not linear.

From different perspectives, including philosophy, psychology, sociology, and education, TPI refers to the perceptions, views, beliefs, emotions, motivations, and attitudes that teachers have about their roles, and can comprise the purpose and central qualities of an individual teacher, framed in subject knowledge, competence, performance, life stories, professional development, and context (Davey, 2013; Day et al., 2006; Rodrigues & Mogarro, 2019). TPI can be regarded as the “core of the teaching profession,” which allows teachers to “construct their own ideas of ‘how to be,’ ‘how to act’ and ‘how to understand’ their work and their place in society” (Sachs, 2005, p. 15). Thus, TPI can be defined by personal attributes (e.g., science teacher competence) and social attributes (e.g., belonging to a science teacher community).

Given our focus on science teacher identity for this scoping review, TPI is a reasonable framing. TPI is helpful for understanding teacher learning and development, and likewise, science teacher support and training for long-term retention (Avraamidou, 2014a). As Suarez and McGrath (2022) note, “existing international evidence

shows that these positive outcomes of TPI persist across different countries and economies” (p. 14). Teachers who are more aware of their professional identities are more likely to manage varied expectations and changes in evolving, challenging teaching contexts, engage in high-quality teaching, and remain in the profession (Rushton & Reiss, 2021). This framework recognizes that teachers’ commitment to teaching and their self-efficacy—especially amongst diverse, shifting priorities, expectations, and levels of support—are important parts of their professional identities that critically affect students’ performance and attitudes (Suarez & McGrath, 2022).

Overall, this conceptual framework offers a comprehensive, holistic image of TPI, connecting the educational system and school context, structures and support, teacher behaviors and attitudes, and student outcomes. It is important to understand how these parts of the system interact to impact teacher practice and ultimately outcomes. This framing of TPI aligns with important considerations outlined in previous reviews, from the key features and theoretical frameworks of teacher identity by Feser and Haak (2023) to the role of context (Avraamidou, 2014a) across multiple scales (Danielsson et al., 2023) and group level processes in identity formation and development (Rushton & Reiss, 2021).

Methodology

We chose to conduct a scoping review of science teacher identity research to (1) clarify key concepts or definitions in the literature and (2) identify key characteristics or factors related to science teacher identity, which are two characteristics of scoping reviews (Peters et al., 2020). Our approach to the scoping literature review was

systematic and shared many characteristics of systematic literature reviews (Munn et al., 2018). One key difference between a scoping literature review and a systematic literature review is the nature of the research questions. Rather than testing specific hypotheses or identifying relationships between specific constructs, a scoping review focuses on the magnitude and scope of the available research literature in a research field. Specifically, it seeks to describe and establish the extent, range, and nature of research evidence in a topic area (Grant & Booth, 2009; Pham et al., 2014). This focus is appropriate given that science teacher identity is a still relatively new, yet rapidly growing field, with diverse lenses and conceptualizations (Feser & Haak, 2023; Rushton & Reiss, 2021).

This scoping review followed Arksey and O'Malley's (2005) five-stage framework and the recommendations and guidance proposed by Levac et al. (2010) and Peters et al. (2020) for scoping literature reviews. The five stages are: (1) stating research questions; (2) identifying relevant studies; (3) selecting studies; (4) charting the data; and (5) collating, summarizing, and reporting results.

Stating research questions

As noted in our introduction, this scoping review seeks to understand the field of science teacher identity research and identify areas of future research. It is guided by four research questions:

1. What were the characteristics of these research studies?
2. What theoretical frameworks of identity were utilized?
3. How was science teacher identity defined?
4. What were the major findings?

Altogether, these research questions offer a holistic view of science teacher identity research by identifying science teacher identity components, factors impacting its development, and the extent, scope, and nature of science teacher identity research.

Identifying relevant studies

Search terms were developed using the PCC (P—Population or participants; C—Concept; C—Context) framework, derived from our research questions, to narrow the

search within the field of science teacher identity. Pollock et al. (2023) recommends the PCC framework as a guide to develop clear, meaningful objectives and eligibility criteria for a scoping review. In this scoping review, P (Population) was teachers, C (Concept) was identity, and C (Context) were science subjects.

The Boolean operators OR and AND were used to combine search terms, as shown in Table 1. We designed the Boolean search strategy as follows: TI (teache* OR educato* OR schoolteache*) AND TI (identity OR identities OR identification OR "professional identity") AND AB (physics OR science OR earth science OR chemistry OR biology). Therefore, some form of teacher and identity had to be in the title of the article, and some form of science subject in the study's abstract.

For inclusion and exclusion of literature, we used several criteria to narrow the scope of the review (see Table 2). Selected publications had to focus on K-12 science subject schoolteachers in preservice or in-service stages and their science teacher identity. Other criteria included publication time periods from 2000 to 2023 and full-text empirical research studies published in English and in peer-reviewed journals. Two online databases were searched: Education Resources Information Center (ERIC) and EBSCO Academic Search Complete (ASC), from January 2000 to April 2023.

We chose 2000 as our starting year for the literature search, consistent with Rushton and Reiss (2021). While Avraamidou (2014a) reviewed literature from 2001 to 2013, she conducted her search in nine leading journals and did not address the same questions as our scoping review. Avraamidou (2014a) noted that there were "minimal findings" prior to this date (p. 150). Our search of literature from 2000 to 2023 therefore extend beyond that of these previous reviews.

Given our focus on science teacher identity, ERIC and ASC, which both offer access to full-text peer-reviewed journals, were suitable databases for our scoping review. ERIC is the world's most widely used and comprehensive education literature indexing system; it is an online library of education research, sponsored by the U.S. Department of Education's Institute of Education Sciences. It is a highly respected database in the field of education, used in both systematic reviews conducted by Rushton and Reiss (2021) and Feser and Haak (2023); it

Table 1 Key search terms

	PCC elements	Search terms
AND	P-teachers C-identity C-science subjects	Teache* OR educato* OR schoolteache* Identity OR identities OR identification OR "professional identity" Physics OR science OR earth science OR chemistry OR biology

Table 2 Inclusion and exclusion criteria

Criterion	Included	Excluded
Population	Articles focused on schoolteachers in various stages (i.e., preservice and in-service)	Articles focused on students or out-of-school teachers
Concept	Empirical studies with a primary focus on science teacher identity	Articles focused on aspects other than science teacher identity (i.e., self-efficacy, PCK, teaching effectiveness)
Context	Articles focused on science subjects, including science, physics, earth science, chemistry, and biology, and K-12 education	Articles focused on non-science subjects or K-12 education
Time frame	Articles published from 2000 to 2023	Articles published before January 1, 2000 or published after May 1, 2023
Publication Type	Full-text empirical research studies in peer-reviewed journals	Not empirical research studies; books and book chapters; editorials, reviews; policy documents from governments and other organizations, theses and dissertations, reports, and conference proceedings
Languages	English	Other languages

includes a vast collection of journal articles, reports, and other educational materials. EBSCO's ASC is a leading resource for scholarly research, and it provides indexes, abstracts, and full-texts from a wide array of humanities, arts, sciences and social sciences disciplines, including science education, with global geospatial coverage that is updated daily.

Selecting studies

We selected published studies to review in a multistep search and screening process. Figure 2 represents the selection process based on the PRISMA–ScR (Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews) statement (Tricco et al., 2018). All yielded articles were collected using Zotero electronic reference management software. The initial search identified 165 articles, including 117 from ERIC and 48 from ASC, among which 37 were duplicates. After removing duplicates, potentially relevant papers were subjected to a two-step screening procedure. During the first step, irrelevant articles were filtered out by reviewing their titles and abstracts. Then, we browsed the titles and abstracts of all search results. The process excluded 68 articles, because they were not the desired publication type (i.e., journal articles), empirical research, related to science teacher identity, or science teachers at K-12 levels. During the second step, after reading the full text, 12 articles were removed, primarily due to the research focus, such as focusing on students and out-of-school educators and preservice educators of out-of-school programs; aspects other than science teacher identity; and non-science subjects. Finally, 48 articles remained for analysis in this scoping review.

Compared to previous literature reviews on the topic, our above literature search resulted in 26, or 54% of the 48, reviewed articles that were not included in the

Avraamidou (2014a), Rushton and Reiss (2021), and Feser and Haak (2023) literature reviews (i.e., Avraamidou 2016a, b, 2019; Badia & Iglesias, 2019; Blackmore et al., 2018; Carrier et al., 2017; Chen & Mensah, 2022; Coddington & Swanson, 2019; Hathcock et al., 2020; Ibourk, 2021; Katz et al., 2013; Khoza, 2022; Luehmann, 2008a; Luehmann & Tinelli, 2008; Madden & Wiebe, 2015; Marco-Bujosa et al., 2020; Munfaridah et al., 2022; Olitsky, 2020, 2021; Pérez Gracia et al., 2019; Purwaningsih et al., 2020; Shwartz & Dori, 2020; Silva et al., 2021; Varelas et al., 2023; Wei et al., 2021; Wilson et al. 2015). Of these 26 studies, 14 were conducted in the U.S., 3 have been in an unidentified southern European country, 2 in Indonesia, and other countries represented include one study each in China, Chile, Israel, Spain, South Africa, and the U.K., reflecting more international representation.

Charting data

A data-charting form in Excel was jointly developed by two of the authors to determine which variables to extract. The data-charting form captured the following relevant information of published studies: (a) basic information of study, such as authors, year of publication, country where the study was conducted, school location, and discipline; (b) characteristics of participants, such as teachers' grade level, career stage, race/ethnicity, and gender; (c) theoretical framework of the study (explicit or implicit, and if explicit, what framework); (d) definition of identity (explicit or implicit, and if explicit, what category of identity definition); (e) the study's research problems and questions; and (f) key research findings. In the subsections that follow, we offer an overview of the coding definitions and processes for the codes that require more interpretation, such as coding of theoretical frameworks, definition of identity, and research problems and

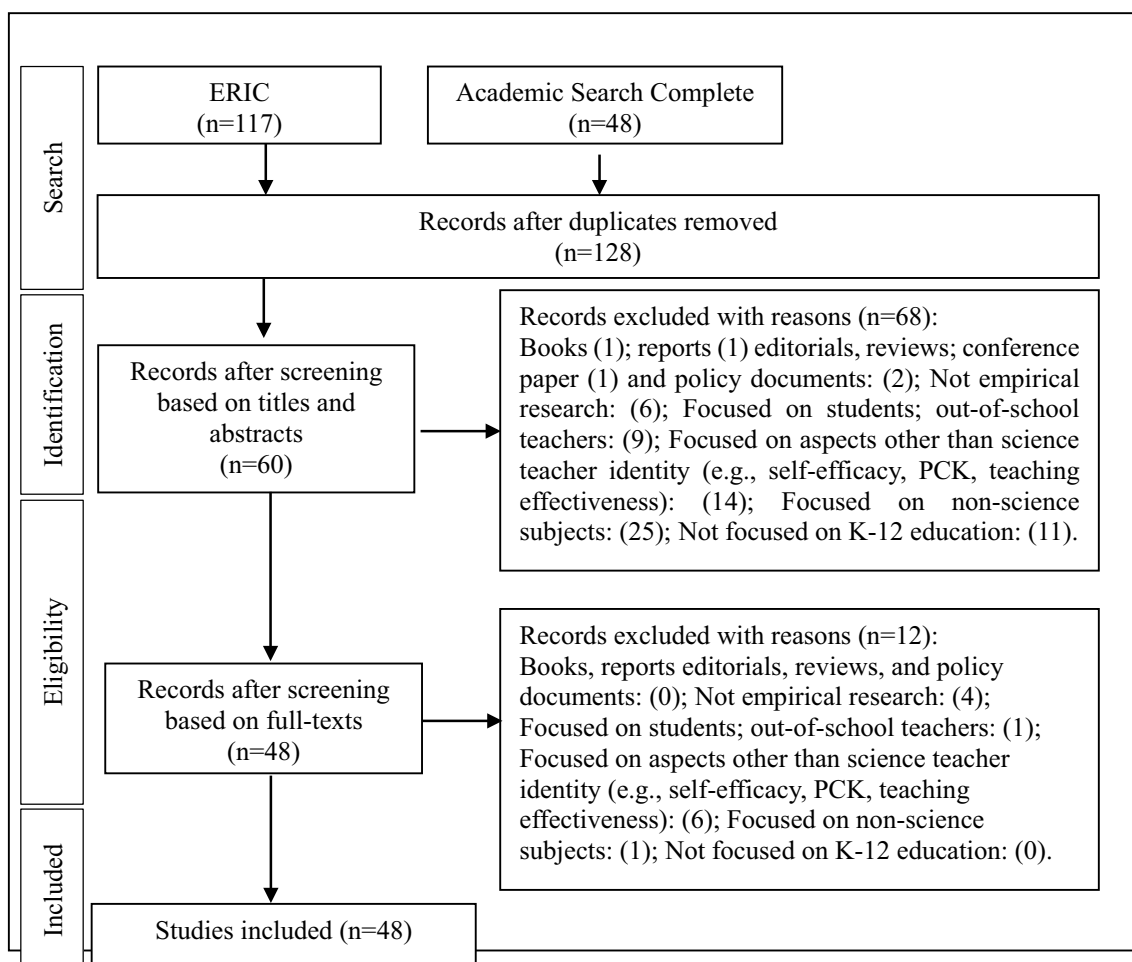


Fig. 2 PRISMA–ScR flowchart for science teacher identity research

questions, before discussing ways in which we sought to enhance reliability of our coding processes.

Coding of theoretical frameworks

Theoretical frameworks of studies were first coded as either having an explicit or implicit theoretical framework. An article was coded as having an explicit theoretical framework if it contained a clear statement of a theoretical framework specifically about identity. If an article did not have a theoretical framework section; the discussion within the study did not clearly subscribe to, delineate, elaborate, and connect to a specific theoretical framework; or the study referred to several theoretical framings and conceptual frameworks in ways that were unclear as to what theoretical tenets were adopted, they were coded as having an implicit framework. To be clear, studies classified as implicit might have had multiple conceptual framings and theoretical influences. Other articles coded as having implicit frameworks might have explicitly stated the theories they drew from, but often,

these studies cited previous literature in making general statements about or defining identity and other constructs pertinent to their study, while the theoretical framework and its use were nonexistent or implicit (e.g., Forbes & Davis, 2008; Silva et al., 2021). Studies were also coded according to theoretical frameworks cited, such as Gee (2000), Holland et al. (1998), Lave and Wenger (1991), Stryker and Burke (2000), and Wenger (1998).

Coding of identity definitions

Studies were coded as having explicit or implicit definitions of science teacher identity. For studies with implicit definitions, some authors mentioned teacher identity definitions provided by others, but they did not specify which of them they adopted in their study of science teacher identity. Moreover, some of the authors did not provide a definition of teacher identity, whether it be by others or their own definition.

Identity can be defined in different ways. According to Darragh (2016), the definitions of identity can be divided

into five categories: participative, narrative, discursive, psychoanalytic, and performative. Psychoanalytic identity is based on psychoanalysis in psychology to make meaning from unconsciousness; no published studies used this definition explicitly or implicitly. Thus, the following discussion excludes psychoanalytic identity, and coding of identity definitions relied on participative, narrative, discursive, and performative categories.

Participative identity refers to the ways in which identity is constructed through participation and engagement in a social group (Darragh, 2016). Authors who explicitly or implicitly adopted this definition typically cited Lave and Wenger's (1991) and Wenger's (1998) notion of "communities of practice" and view identity as "a layering of events of participation and reification by which our experience and its social interpretation inform each other" (p. 151).

Narrative identity refers to the stories which people tell and relate. In this view, identities are narratives about who we are, to whom we adhere, and what positions we hold. Individuals primarily make meaning of their experiences through narrative (Riessman, 1993). In the telling of their personal stories, individuals create meaning, define values in relation to this meaning, and incorporate beliefs into the process of becoming a particular type of person. This personal construction of stories and significant life events is the process of situating and identifying oneself in a specific social world (Sfard & Prusak, 2005).

Discursive identity refers to an understanding of identity as constructed and negotiated through language and discourse. It emphasizes the role of discourse and language practices in shaping how individuals understand and present their identities. Relatedly, identity as subjectivity is the construction of positioning oneself in discourse and of being positioned by discourse, both as subject and object, and is associated with recognition. This definition is influenced by Gee's (2000) theory on "the spoken and written words, semiotic systems, representations, and gestures of participants as they use language to communicate, interact, and act" (Bishop, 2012, p. 44). Therefore, discursive identity is connected to the ways people treat, talk about, and interact with one another, which is also influenced by institutions.

Performative identity is derived from Butler (1988, 1997), who explored the concept of "performativity" and its influence on identity formation. She argued that gender, as well as other aspects of identity, are not fixed but rather performed and constructed through repeated actions and behaviors. Butler's work expands the understanding of performative identity beyond achievement-based domains. This definition is also related to Goffman (1969, 2023), which proposed the concepts of "impression management" and

"dramaturgy" in arguing that individuals actively present themselves in certain ways to others, employing various performances and strategies to shape how they are perceived. Goffman's ideas also shed light on the performative nature of identity and the role of self-presentation in constructing a performative identity. Positional identity, which refers to the social roles, statuses, and positions an individual occupies within a particular context or society, is consistent with this definition. It is impacted by external factors such as job titles, educational qualifications, social roles (e.g., parent, teacher), and other identifiers that give individuals a sense of their position or place in society. Positional identity is often conferred by external recognition or formal designations.

Coding of research problems and questions

The research questions in the 48 studies were classified into three categories: identity process or development, identity factors, and identity nature. Specifically, studies on identity process are concerned primarily with the process or development of identity, although factors impacting the process may also be studied. This category of studies typically involved data collection at multiple time points to document the changes in teacher identity development or transformation. Studies in the category of impact factors are concerned with identifying specific factors or contexts that influence teacher identity development. This category of studies typically uses quantitative cross-sectional surveys or multiple case studies at one time point. Finally, studies in the category of identity nature are concerned with the clarification (e.g., characteristics) of the science teacher identity construct.

Coding reliability

Two authors participated in the coding process. Cohen's weighted Kappa was used to evaluate inter-rater reliability. Initially, the two authors independently extracted data from the same 10 randomly selected articles, and Cohen's Weighted Kappa was calculated (Fleiss & Cohen, 1973; Fleiss et al., 2013). The coefficients of Cohen's Weighted Kappa for all coding categories were 1.0, with the exception of the research questions category (0.348) and the race or ethnicity of teachers' category (0.568). The two coders discussed inconsistencies on these two coding categories, and a revised definition and coding scheme for these two categories were created. Using the revised coding scheme, the two coders independently coded another 10 randomly selected articles and then calculated the inter-rater reliability again. The coefficients of Cohen's Weighted Kappa for all coding categories were 1.0.

Collating, summarizing, and reporting findings

Descriptive statistical (e.g., frequency distribution) analysis was conducted to answer research question 1; to answer research questions 2–4, related codes were grouped into thematic categories as described in the previous section. Studies coded within the same category were revisited, and related information was collated, read, and summarized to develop thematic categories. Details from articles exemplifying particular thematic categories, or divergences, were noted. Checks were made within and across these categories, and narrative descriptions were combined to report findings. Discussions among the authors helped to resolve questions and discrepancies in interpretation through consensus coding.

Limitations

Due to our methodological approach, our scoping literature review has several limitations that should be considered. First, we recognize that there are pros and cons for any database used; we might have missed important studies that are not indexed by ERIC and ASC, are not peer-reviewed journal articles, and/or published in languages other than English. As with Rushton and Reiss (2021), our review does not contend with educators who teach individuals beyond high school.

Our review also focuses on science schoolteachers and preservice teachers, who teach in formal school settings, and therefore empirical research focused on out-of-school science teachers and preservice teachers of informal science educator preparation programs have been

excluded (e.g., Adams & Gupta, 2017). Although this criterion allowed for the inclusion of studies that explore the role of informal science education contexts, such as after school and summer programs, on the development of participants’ science teacher identities (e.g., Katz et al., 2011; Silva et al., 2021), we recognize this exclusion criteria decision might limit our understanding of informal science teachers’ identities more broadly. Finally, we acknowledge that our search criteria might have missed other studies without some form of “teacher” and “identity” in the title or science subject in the abstract, though the decision to search for these terms in the title and abstract was made to ensure that science teacher identity was core to the articles reviewed.

Results

This section presents the findings of our scoping review, organized according to research questions.

Research question 1: characteristics of science teacher identity studies

As shown in Fig. 3, the number of empirical articles on science teacher identity has steadily increased since 2008 after a period of flattening, indicating the increased attention science teacher identity research has garnered. In particular, 30 articles, or 63% of the 48 included studies, were published after 2013, the end year of Avraamidou’s (2014a) literature search, and 13 articles or 27% were published in or after 2020, which extend past the end years of the Rushton and Reiss

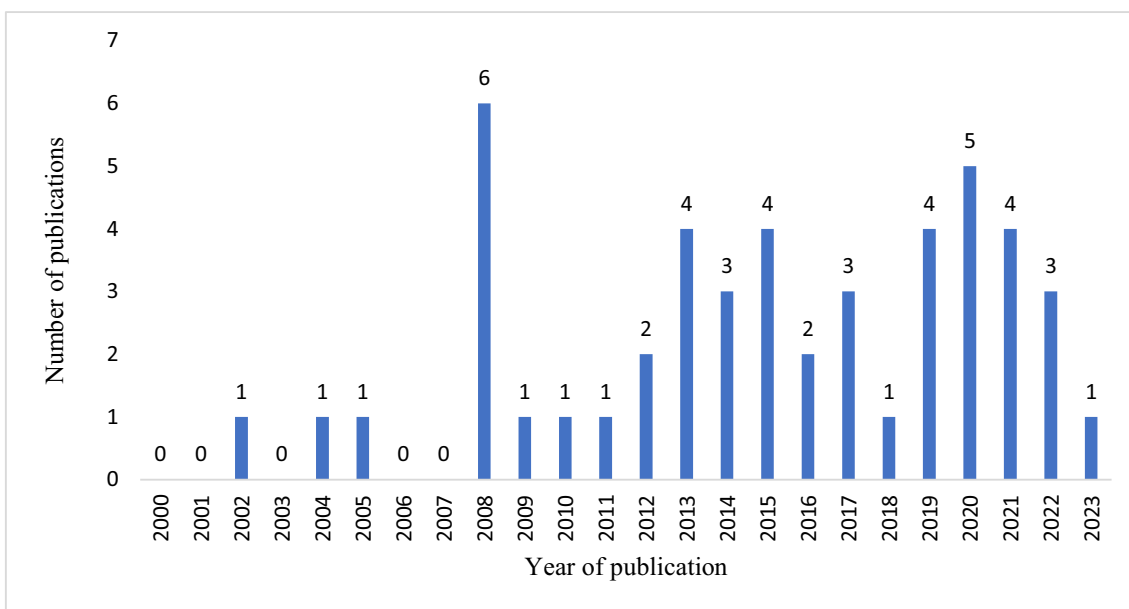


Fig. 3 Number of science teacher identity articles distributed across publication year from 2000 to 2023

(2021) and Feser and Haak (2023) systematic reviews. This distribution signifies the rapid growth of the science teacher identity field within the last ten years.

Figure 4 reveals that most studies on science teacher identity were conducted in the United States (U.S., 64.6%). Following the U.S., the distribution of studies includes the United Kingdom (8.3%), an unidentified Southern European country (8.3%), Indonesia (4.2%), and South Africa, as well as Brazil, Chile, China, Israel, New Zealand, and Spain (2.1% each). The country distribution indicates a relatively widespread international research interest in science teacher identity. Except for studies in the U.S., China, and Indonesia, studies from other countries did not provide information about school settings. U.S. studies were conducted in mostly northeastern and southeastern contexts. Among the research studies in the U.S., where settings were identified, 64.5% were conducted in school settings, with 13 studies in urban schools, 1 in suburban schools, 4 in both urban and suburban schools, and 2 in rural schools. The one study conducted in China, Wei et al. (2021), occurred in a suburban area of a provincial capital city in a western province. The context of the Purwaningsih et al. (2020) study was a public university physics teacher preparation program, with the pre-service teacher's placement in a public high school in Malang, Indonesia.

The research studies encompassed a wide range of disciplines. The general science subject accounted for a majority of studies (64.6%), while specific science subjects such as physics, chemistry, and biology or environmental science, made up 6.3%, 4.2%, and 2.1%, respectively. In addition, 22.9% of the studies were multidisciplinary, i.e., involving two or more of the abovementioned disciplines. Regarding the distribution of grade levels, the published studies exhibited a relatively balanced representation, with 39.6% focused on elementary school and 43.8% on secondary school, which includes middle and high school contexts.

In terms of research methodology, the majority of studies were qualitative (85.4%), while three articles (6.3%) were solely quantitative, and four (8.3%) were mixed-methods. Qualitative studies were predominantly case studies following interpretivist traditions, including ethnographic, narrative, and phenomenological case studies, and relied on semi-structured interviews, observations, and artifacts such as blog posts, e-mail exchanges, journal entries, and lesson plans, among others (e.g., Dominguez et al., 2015; Luehmann, 2008b; Silva et al., 2021; Upadhyay, 2009). Quantitative studies employed instruments with Likert, multiple-choice, and open-ended response formats (Badia & Iglesias, 2019; Munfaridah et al., 2022; Pérez Gracia et al., 2019). Mixed-methods studies used surveys and questionnaires with close-ended and

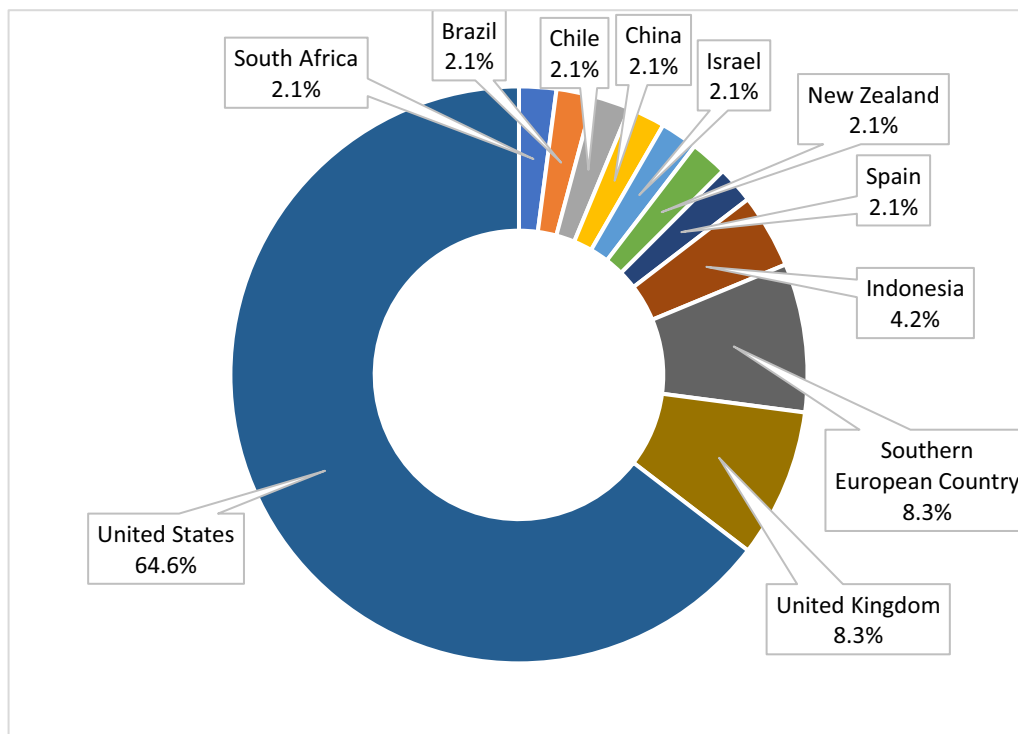


Fig. 4 Science teacher identity research distribution by country

open-ended response formats, focus groups, semi-structured individual interviews, journal entries, and observations (Blackmore et al., 2018; Forbes & Davis, 2008; Shwartz & Dori, 2020; Woolhouse & Cochrane, 2015).

There were 39 (81%) of studies that utilized interviews; only 6 (13%) included interviews with other stakeholders besides science teachers. It is important to note that compared to interviews, observations were less commonly used research methods. There were 18 (38%) of studies that utilized observations; most studies relied on 1 to 10 observations, such as the 2, 15-min lessons taught to preservice science teacher peers in a methods course (Rivera Maulucci, 2013), except for 26 lessons observed in Wei et al. (2021) and 49 h of observation in Naidoo (2017).

Reviewed quantitative and mixed-methods studies reveal a need for instruments dedicated to science teacher identity, with enhanced psychometric properties that attend to validity, reliability, and fairness. For example, in their 2019 study, Pérez Gracia et al. developed an instrument for measuring the beliefs of future science and technology teachers regarding their understanding of teacher professional identity (TPI). The S-TPI instrument encompasses four dimensions: elements defining TPI, its development at different educational stages, the contrast in identity construction between teachers and other professionals, and factors contributing to TPI development. However, the article could benefit from providing a clear theoretical framework for the instrument and integrating these four dimensions effectively with the framework.

Munfaridah et al. (2022) adopted an adapted version of a physics identity questionnaire to measure the development of three identity components: interest, performance, and recognition based on a combined framework of physics identity proposed by Carlone and Johnson's (2007) and Hazari et al.'s (2010) frameworks. However, the target sample of the measurement instrument was university students, and the reliability of the performance sub-scale was not as strong, with the Cronbach's α rather unsatisfactory at 0.56. Badia and Iglesias (2019) described three clusters of science teacher identities using indicators about teachers' conceptions of teaching and learning, which contribute to science teacher identity. However, this study did not provide a valid and reliable instrument to measure science teacher identity.

Besides these quantitative studies, there were four mixed-methods studies. Three of them used surveys to obtain both quantitative and qualitative data, and none included an instrument for measuring science teacher identity (i.e., Blackmore et al., 2018; Shwartz & Dori, 2020; Woolhouse & Cochrane, 2015). Forbes and Davis (2008) used a survey instrument to measure preservice teachers' developing curricular role identity for science teaching to obtain a gross measure of role identification,

but they did not provide any reliability and validity information about the instrument.

The studies examined teachers at various stages of their careers, with 50.0% focusing on preservice teachers, 37.5% on in-service teachers, and 12.5% on both preservice and in-service teachers. The gender distribution of participants revealed that 54.2% involved both male and female teachers, 37.5% exclusively involved female teachers, and 8.3% solely male teachers; no studies reported non-binary science teacher participants. Thus, the science teacher identity research in our scoping review predominantly centered on female and preservice science teachers. The majority of studies, or 72.9%, focused on racially heterogeneous groups of science teacher participants, or teachers of multiracial or unreported racial backgrounds, while 10.4% comprised White, 6.3% Black, 6.3% Native, and 4.2% Asian or Pacific Islander teacher participants only.

Research question 2: theoretical frameworks of science teacher identity studies

Analysis of the theoretical frameworks of the 48 publications found that 22 (46%) of the articles had an explicit theoretical framework of identity, and 26 (54%) did not have an explicit theoretical framework of identity. Among the articles that had an explicit theoretical framework of identity, 12 relied on Gee's (2000, 2003) sociocultural identity theory (Akerson et al., 2014; Avraamidou, 2014b; Carrier et al., 2017; Katz et al., 2011; Luehmann, 2008a; Madden & Wiebe, 2015; Marco-Bujosa et al., 2020; Purwaningsih et al., 2020; Saka et al., 2013; Upadhyay, 2009; Varelas, 2005; Wei et al., 2021); 5 utilized Wenger (1998), Lave and Wenger (1991), and Lave (1996), drawing upon situated learning theory and communities of practice (Chen & Mensah, 2022; Coddington & Swanson, 2019; Naidoo, 2017; Wilson et al., 2015; Woolhouse & Cochrane, 2015); 2 used social psychology theories of identity with sociological underpinnings (Hathcock et al., 2020; Olitsky, 2020); and 1 referenced Holland et al.'s (1998) figured worlds (Moore, 2008b). Moreover, Avraamidou (2016b) explicitly stated that she drew from Connelly and Clandinin's (1999) conceptualization of the professional identity of teachers, while Munfaridah et al. (2022) explicitly cited Carlone and Johnson (2007) and Hazari et al. (2010) for their theoretical framework on physics identity.

In the sections that follow, we delve more deeply into the explicitly identified theoretical frameworks in order of prevalence in our scoping literature review: (1) Gee's sociocultural identity theory, (2) Lave and Wenger's situated learning theory and communities of practice, (3) social psychology theories of identity; and (4) Holland and colleagues' theory of figured worlds. We begin each

of these subsections with a brief introduction to these frameworks and then note studies that utilize these theoretical frameworks for studying science teacher identity.

Gee's (2000) sociocultural theory of identity

According to Gee (2000), identity is being “recognized as a certain ‘kind of person’ in a given context” (p. 99). In this sense, a person’s multiple identities are tied to their performances in society rather than their internal states. A person’s identity can change through interaction, across context, and “be ambiguous or unstable” (p. 99). Gee (2000) proposed four perspectives to view identity: Nature-Identities, Institution-Identities, Discourse-Identities, and Affinity-Identities. Specifically, *Nature-Identities* refers to a state developed from forces in nature; *Institution-Identities* refers to a position entitled by authorities within institutions; *Discourse-Identities* refers to an individual trait recognized in the discourse or dialogue with others; and *Affinity-Identities* refers to the experiences shared in the practice of affinity groups. Throughout his work, Gee (2000) emphasized the role of recognition in generating identity, as “human beings must see each other in certain ways and not others if there are to be identities of any sort” (p. 109). Like situated learning and CoP, Gee’s (2000) identity theory is sociocultural; it emphasizes the close relationship between identity and historical, institutional, and sociocultural forces.

The predominant focus of research employing Gee’s (2000) theoretical framework of identity was on the formation, development, and incorporation of science teacher identity. These studies emphasized the diverse perspectives of identity and the various personal and contextual factors that influenced an individual’s identity. For instance, Marco-Bujosa et al. (2020) stated that the utilization of Gee’s theory of identity provided insights into the experiences of an in-service bilingual classroom teacher at a school for children who are Deaf in the U.S. Through adopting this theoretical framework, researchers conducted a thorough examination of a White female elementary teacher’s science teacher identity development, as she navigated the process of learning to teach science, against the backdrop of pressures to prioritize literacy and American Sign Language, which were viewed as disconnected from science learning. Meanwhile, this framework also recognized the wide range of personal and contextual factors that contributed to her identity development. Akerson et al. (2014) utilized Gee’s Institution-Identities and Discourse-Identities for their analysis of a science education methods professor who returned to the elementary classroom to teach science through a NOS perspective.

Lave and Wenger’s (1991) situated learning theory and Wenger’s (1998) communities of practice (CoP)

Lave and Wenger’s (1991) situated learning theory provides a theoretical framework for understanding identity formation as a learning process. Situated learning theory places significant emphasis on the following key principles: (a) Legitimate peripheral participation: Novices initially engage in legitimate peripheral participation, where they observe and gradually become more involved in the community’s activities. Through this process, individuals transition from being newcomers to active members, shaping their identities along the way; (b) the inseparability of identity and learning: identity is formed through individuals engaged in learning within CoP; (c) the role of social interaction: through social interactions, individuals negotiate their roles, gain a sense of belonging, and construct their identities as they become more integrated into the community; (d) Identity Negotiation: as individuals engage in various activities and interactions, they negotiate their roles and identities. Negotiation is a continuous process that involves adapting to new challenges, redefining one’s sense of self, and evolving within the CoP. In essence, Lave and Wenger’s (1991) situated learning theory and Wenger’s (1998) CoP suggest that individuals dynamically form identities within specific social contexts and CoP. Learning involves a transformation of identity as individuals engage in activities through ongoing participation and interaction. Through participation in joint activities, interacting with others, and contributing to knowledge in communities, individuals develop identities that are intertwined with the collective identities of communities (Wenger, 1998).

For example, Naidoo (2017) adopted situated learning theory as a theoretical framework and proposed that learning contributed to the development of an elementary science teacher candidate’s identity. Naidoo approached the process of identity formation as a dialogical process that occurred between individuals rather than being limited solely within individuals. The utilization of this theoretical framework allowed the author to capture the dynamic nature of identity formation within a science methods course designed for preservice science teacher candidates. Chen and Mensah (2022) incorporated the theoretical frameworks proposed by Lave and Wenger (1991) as well as Wenger (1998). The authors assumed that learning to teach science involved not only an accumulation of knowledge and skills but also a process of becoming a certain kind of person within a CoP. In this way, legitimate peripheral participation for elementary teachers can be understood as a way of learning that involves both absorbing and becoming fully engaged in a culture of practice. As their practices and participation evolved, preservice science teachers moved towards

becoming part of the science teaching community and developed an increased sense of identity as science teachers.

Social psychology and sociological theories of identity

Theories of social psychology, underpinned by sociological framings, were also cited in several reviewed studies. One theory proposed by Stryker and Burke (2000) conceptualizes identity as the self-composed meaning that individuals attach to the multiple roles they commonly assume in highly differentiated, contemporary societies. Stryker and Burke identified two processes of identity formation, one being the internal process of self-verification and the other being social structures. They argued that social structures influence the internal process of self-verification, whereas the internal process of self-verification creates and sustains these social structures. During the internal process of identity formation, identity is understood as cognitive schemas, or internally stored information and meanings serving as frameworks for interpreting experience (Stryker & Serpe, 1994). Identities are self-meanings, and self-meanings develop in the context of the meanings of roles and counter-roles (Burke, 1980; Burke & Tully, 1977).

Behavior is commonly understood as a function of the relationship between what a person perceives in situations and the self-meanings held by individuals (Burke, 1997; Heise, 1979; Stets, 1997). In the context of social structures, identity is viewed as the quest of individuals to seek validation by actively seeking or constructing situations that allow for the expression of their true selves. Both processes consider identities as linked to roles and behaviors through the attribution of meaning. It is possible for individuals to obtain stable and constant psychological centrality (Stryker & Burke, 2000).

Olitsky (2020) employed identity theory (Stryker & Burke, 2000) to highlight the significance of consistency between an African American science teacher's self-perceptions and external feedback from others in facilitating the process of identity development. Working in a particular institution can be viewed as an act of identification with a professional community, and lack of alignment can be a factor in a person's decision to leave their position as a science teacher. In addition, Hathcock et al. (2020) used the Dynamic Systems Model of Role Identity (DSMRI) by Kaplan and Garner (2017). The DSMRI depicts role identity as a complex, dynamic system in which a teacher acts, comprising four interdependent components: (a) self-perceptions and self-definitions; (b) ontological and epistemological beliefs; (c) purpose and goals; and (d) perceived action possibilities (Kaplan & Garner, 2017; Maehr & Braskamp, 1986). With this framework, Hathcock and colleagues were able to explore both the teacher

and context, their sub-identities, and the agentic pursuit of learning goals, which could differ and be in tension with reform-oriented professional development goals.

Holland et al.'s (1998) identity and agency in cultural, figured worlds

Holland et al.'s (1998) framework focuses on the processes through which individuals construct their identities in cultural worlds. It provides a perspective for comprehending how individuals navigate their social surroundings, utilizing cultural models to construct identities and exercise agency, which is the capacity of individuals to take actions, make choices, and shape identities. Individuals actively participate in the process of engaging with figured worlds, or socially constructed frames of reference that recognize certain types of people, acts, and outcomes as celebrated and meaningful. Figured worlds are constructed through interaction and guide individuals to act in certain ways, among certain possibilities that are afforded to them, governed by cultural norms, social structures, and power dynamics within the figured worlds.

Moore (2008b) utilized Holland et al. (1998) to conceptualize the construction of three African American science teachers' identities in relation to others and within multiple social structures. Moore (2008b) used this framework for positional identity, which was essential, because it provided a framework for understanding teachers on an individual level based on their life experiences in culturally constructed worlds (e.g., race, gender, class, ethnicity, age, and religion), their classroom practices, and their professional development. It allowed for insights into how they negotiated power and their roles as science teachers.

Summary of theoretical frameworks

Research studies on science teacher identity mostly had implicit theoretical frameworks and mostly employed several similar theoretical frameworks. These frameworks include sociocultural perspectives, which encompass the theories of Gee (2000), Wenger (1998), Lave and Wenger (1991), and Lave (1996). To a lesser extent, studies employ social psychology and sociological perspectives, such as those represented by Kaplan and Garner (2017), Stryker and Burke (2000), and Stryker and Serpe (1994), as well as Holland et al. (1998), which takes on social anthropology and cultural psychology lenses.

These perspectives share the understanding of the social, contextualized nature of identity and emphasize the significance of social interactions in identity development. However, these perspectives differ in their focus, level of analysis, and emphasis on cultural factors. The sociocultural perspectives are informed by sociocultural

theories and highlight the impact of cultural and social contexts, including practices, norms, and values, on identity development. In addition to acknowledging the role of culture, social psychology perspectives also place emphasis on individual-level psychological processes, giving significance to both cognitive and social aspects of identity formation and meaning, while also attending to the impact of structures.

Regardless of whether studies had explicit or implicit theoretical frameworks, they recognized that science teacher identity is historically and socially constructed, multifaceted, complex, and influenced by context, although the focus primarily was on teachers' immediate school contexts. Given the overlap and similarity of these theories, often studies (e.g., Forbes & Davis, 2008; Ibourk, 2021; Luehmann, 2008a; Moore, 2008a; Varelas et al., 2023) cited several of these frameworks, although the extent to which they elaborated on the main tenets and drew on these frameworks varied. As such, the theoretical frameworks that are frequently cited share many similarities. First, they highlight connections among the past, present, and future of identity, establishing a temporal dimension. As Wenger (1998) states, identity "has a coherence through time that connects the past, the present, and the future" (p. 154), which is similar to Sfard and Prusak (2005), which distinguishes actual (current) from designated (future) identities in stories. Holland et al. (1998) similarly discuss reinterpreting the past and imagining future figured worlds. Gee (2000) speaks to history and future as well. In social psychology theories, such as Kaplan and Garner (2017), past, present, and future role identities are recognized. In these ways, the frameworks in science teacher identity studies attend to temporal dimensions of identity and regard it as changing through experience and practice, while embedded in social contexts with certain norms, rules, expectations, and degrees of recognition.

Gee's (2000) theory places particular emphasis on the significance of language, discourse, and social practices in the process of constructing one's identity. This theory draws extensively from the fields of sociolinguistics and discourse analysis. Wenger (1998), Lave and Wenger (1991), and Lave (1996) highlight the significance of participation in social practice communities for the development of learning, meaning, and identity. The importance of social interactions, shared practices, and the development of a sense of belonging is emphasized. Holland et al. (1998) draw most heavily from sociocultural theories of Bakhtin, Vygotsky, and Wertsch, while also acknowledging similarities and influences from the work of Bourdieu regarding capital, fields, and habitus; Davies, Harré, and van Langenhove with positioning theory; and intersections with Lave and Wenger in terms of CoP, among

others. Overall, there is considerable overlap with other theories and theorists within Holland et al. (1998). The primary emphasis of Holland et al. (1998) revolves around the field of cultural psychology and social anthropology and its exploration of the impact of cultural environments on the development of identity and agency.

There is also great emphasis across the sociocultural frameworks on identity as a process—as tentative and an ever-changing action—to the exclusion of recognizing identity as an attribute, or the stability of identity that thickens over time, instead of recognizing that such core facets are representative of moments in time. For example, Wenger (1998) refers to identity as "not an object, but a constant becoming" (pp. 153–154) and focuses on identities-in-practice. In speaking about identity formation and development, Holland et al. (1998) discuss "identity-making processes" (p. 3), and Gee (2000) emphasizes interactions, including processes to be recognized as a certain kind of person. All frameworks acknowledge limits of structures in furthering recognition, performance, and authoring of identities to some extent, although the social psychology theories more prominently and explicitly make these connections. The sociocultural and social anthropology theoretical frameworks primarily emphasize individual agency in constructing identities, albeit situated in social contexts and in relation to others.

Research question 3: definition of science teacher identity

Twenty-two of the articles (46%) had explicit definitions of teacher identity, while 26 (54%) did not have explicit definitions of teacher identity. In what follows, we present a table of results and further elaboration on examples of studies according to the definition categories: participative, narrative, discursive, and performative. Table 3 details the results from categorizing the definitions of teacher identity in the 48 articles included in this review.

Participative identity

Studies that define identities as participative may concentrate on two levels of identity: individual identity and collective identity. The relationship between these two identities is crucial to the formation and development of teacher identity. For instance, Coddington and Swanson (2019) explicitly drew on Wenger's (1998) CoP and Cobb et al.'s, (2009) conceptualization of normative and personal identities. Normative identity is the collectively perceived set of expectations for how individuals are perceived to be competent in a given context, whereas personal identity represents how individuals develop as they engage in the practices within a specific context. In this study, the negotiation of the two identities was highlighted. When normative identity expectations and an

Table 3 Science teacher identity articles distributed by definition category

Category		Number of Articles	Articles
Implicit Definition	Participative identity	4	Blackmore et al. (2018), Eick and Reed (2002), Pérez Gracia et al. (2019), Woolhouse and Cochrane (2015)
	Narrative identity	14	Avraamidou (2016b), Danielowich (2012), Edwards and Edwards (2017), Katz et al. (2011), Luehmann (2008a), Moore (2008a), Olitsky (2020, 2021), Proweller and Mitchener (2004), Silva et al. (2021), Siry and Lara (2012), Upadhyay (2009), Varelas et al. (2005, 2023)
	Discursive identity	8	Allaire (2013), Badia and Iglesias (2019), Carrier et al. (2017), Chen and Mensah (2022), Danielsson and Warwick (2014), Katz et al. (2013), Madden and Wiebe (2015), Naidoo (2017)
	Performative identity	0	
Explicit Definition	Participative identity	5	Akerson et al. (2014), Avraamidou (2019), Coddington and Swanson (2019), Forbes and Davis (2008), Shwartz and Dori (2020)
	Narrative identity	5	Avraamidou (2016c), Dominguez et al. (2015), Ibourk (2021), Wilson and Deaney (2010), Wilson et al. (2015)
	Discursive identity	9	Avraamidou (2014b), Hathcock et al. (2020), Khoza (2022), Luehmann (2008b), Luehmann and Tinelli (2008), Marco-Bujosa et al. (2020), Purwaningsih et al. (2020), Saka et al. (2013), Wei et al. (2021)
	Performative identity	3	Moore (2008b), Munfaridah et al. (2022), Rivera Maulucci (2013)

individual's abilities for their anticipated future are not negotiated well, the development of a science teacher's identity can present difficulties or obstacles. Even within similar or identical contexts, science teachers' identity development trajectories were not identical due to the distinct ways in which they negotiated their normative and personal identities.

Studies that define identities as participative may also emphasize the ongoing negotiation process during identity formation. In the negotiation process, the significance of an individual's life experiences may also be highlighted (e.g., Eick & Reed, 2002; Forbes & Davis, 2008; Pérez Gracia et al., 2019; Woolhouse & Cochrane, 2015). For example, Pérez Gracia et al. (2019), with an implicit definition of teacher identity, emphasized that the construction of a teacher's professional identity could be considered a process of negotiating various teaching concepts, which are enriched through interacting with other teachers. Likewise, the study by Woolhouse and Cochrane (2015), though it did not provide an explicit definition, viewed trainees' abilities to negotiate policy demands in order to develop a professional identity as an essential factor in the formation of teacher identities. Negotiation in the process involved dealing with gaps between teachers' desired identities and their classroom experiences as preservice science teachers.

Despite the lack of a precise definition of teacher identity, Eick and Reed's (2002) description of science teacher identity was consistent with the view that a new teacher's role identity is formed by experiences as young students, previous teaching experiences, teacher role models, and other significant people (Cole, 1990; Knowles, 1992).

According to the authors, a preservice teacher's personal history in education and ensuing belief systems serve as a foundation for early career teacher identity. Personal history impacts the strength of the initial role identity (Knowles, 1992).

Furthermore, studies that define identity as participative may emphasize the role of attitudes, beliefs, and values within teachers' practices and learning processes (e.g., Blackmore et al., 2018; Pérez Gracia et al., 2019; Shwartz & Dori, 2020). For instance, Shwartz and Dori (2020) explicitly conceptualized TPI as a process of reconciling the personal and professional sides of becoming a teacher and emphasized that professional identity is influenced not only by teachers' personal characteristics but also by professional contexts, such as their education program, knowledge, skills, prior experiences, and educational attitudes. In another study by Pérez Gracia et al. (2019), professional identity referred to the specific roles, objectives, and teaching styles that preservice science and technology teachers aspire to assume as part of their professional development. Teachers' beliefs, values, and attitudes regarding the teaching and learning processes in their respective subject areas were emphasized as conceptual connotations of TPI. Similarly, in spite of the absence of an explicit definition, Blackmore et al. (2018) identified trainees' attitudes towards science teaching as significant aspects of their TPIs. Notably, studies that define identity as participative study the processes of preservice and novice teachers becoming teachers (e.g., Blackmore et al., 2018; Coddington & Swanson, 2019; Eick & Reed, 2002; Forbes & Davis, 2008; Pérez Gracia et al., 2019), and that of career changers, or individuals

who transition to teaching from other professions (e.g., Akerson et al., 2014; Shwartz & Dori, 2020).

Narrative identity

In studies implicitly or explicitly defining science teacher identity as narrative identity, there is a premise that individuals give meaning to their daily lives as stories that are shaped by and unfold in their natural surroundings. Teacher identity emerges from an individual's interpretation and reinterpretation of experience in multiple contexts, which is the individual's process of giving the events meaning. At this level, the primary way for individuals to comprehend experience is through narrative presentation (Riessman, 1993), and it is also through this process that individuals create meaning, which is integrated into the process of someone acquiring a particular identity, e.g., becoming a science teacher.

Studies with narrative identity definitions underscored that one's identity construction is an ongoing, evolving process. Individuals actively shape their identities through the narratives they create and revise as they grow and encounter new experiences (e.g., Avraamidou, 2016b, c; Edwards & Edwards, 2017; Moore, 2008a; Siry & Lara, 2012). Avraamidou (2016c), with an explicit definition, conceptualized identity as a tentatively shaped and socially situated construct, which is under development and subject to change. Siry and Lara (2012), with an implicit definition, also viewed identity as fluid, as one engages in activity and makes sense of these experiences. Similarly, although Edwards and Edwards (2017) did not provide an explicit definition, they viewed teacher identity and its development as a complex construction process that occurs over time, in a range of contexts, and embedded in an array of life experiences, interactions, thinking, and responses of individual teachers over time.

Narrative identity involves the process of meaning-making, where individuals assign significance and interpret their experiences within the context of their personal narratives. It allows individuals to derive a sense of purpose, values, and personal meaning from their life events and choices (e.g., Dominguez et al., 2015; Luehmann, 2008a; Olitsky, 2021; Proweller & Mitchener, 2004; Silva et al., 2021; Varelas et al., 2023; Wilson & Deane, 2010). For example, Varelas et al. (2023) described the construction of teacher identity as a process of learning to teach. The authors opted for a transcendental phenomenological analysis of the phenomenon as it was experienced by teachers to focus on the ways in which teachers experience and construct meaning for the phenomenon of interest, implying that the construction of science teacher identity for teachers is reliant on the meaning they assign to their experiences.

Luehmann (2008a) acknowledged the viewpoint that an individual's series of significant stories constitutes a trajectory through time of becoming a certain kind of person. With this definition, identities are considered constructed, creatively authored, rhetorical, replete with assumptions, and interpretive. Moreover, Dominguez et al. (2015) defined the formation of a science teacher's identity as a socialization process marked by the individual construction (or reconstruction) of symbolic systems, while Wilson and Deane (2010) defined teacher role identity as the meaning teachers give to the characteristics and expectations that simultaneously create a teacher's daily routine.

Narrative identity also emphasizes the significance and centrality of the self through the process of narrating and interpreting significant life events, personal experiences, and relationships; it encompasses the telling and retelling of one's life story, highlighting key moments, turning points, and themes that shape an individual's identity (e.g., Avraamidou, 2016c; Ibourk, 2021; Katz et al., 2011; Olitsky, 2020; Varelas et al., 2005). For instance, Ibourk (2021) provided an explicit definition of storied identities as the identities of teacher candidates shaped by the salient stories of learning science, deciding to become a science teacher, and becoming a science teacher. Other studies that did not provide an explicit definition also emphasized the significance of the self in their descriptions of teacher identity. For example, Katz et al. (2011) demonstrated that identity can be defined as collections of stories about people, as those narratives about individuals are reifying, endorsable, and significant; this study explored science teacher identity by allowing teachers to tell their stories of themselves as teachers of science. Olitsky (2020) also constructed descriptions of identity as parts of the self-composed meanings that individuals attach to the multiple roles they typically play in highly complex, contemporary societies. As narrators, teachers tell their stories, where their identities manifest. As teachers narrate their stories, they negotiate and renegotiate a fluid self in order to understand and define who they are.

Discursive identity

Researchers using a discursive identity definition adopt a multidimensional, holistic perspective of science teacher identity (e.g., Khoza, 2022; Luehmann, 2008b; Luehmann & Tinelli, 2008; Marco-Bujosa et al., 2020; Naidoo, 2017; Purwaningsih et al., 2020). For example, Marco-Bujosa et al. (2020), utilizing Gee's (2000) sociocultural framework, clearly defined teacher identity as consisting of four interrelated dimensions, including Institution-Identity, Discourse-Identity, Affinity-Identity, and Nature-Identity. The authors tracked the emergence and evolution of a

science teaching identity while also acknowledging the numerous personal and contextual aspects that shaped the teacher's identity.

Studies with explicit or implicit discursive identity definitions may incorporate aspects of other identity definition categories (e.g., Carrier et al., 2017; Madden & Wiebe, 2015). For example, with an implicit definition of teacher identity, Carrier et al. (2017) adopted Avraamidou's (2014b) identity trajectory model, which combined elements from Gee's (2000) views of identity with Clandinin and Connelly's (2000) three-dimensional narrative inquiry space model, including interaction–continuity–situation, so as to capture time and space in the three distinct but continuous stages from student to teacher and to examine identity constructs within each stage. Similarly, Madden and Wiebe (2015) deemed that Gee's (2000) framework is focused on 'who a teacher is' rather than 'what a teacher does.' To address the importance of understanding how identity translated into practice, they incorporated a fifth dimension: expertise, which can strengthen their descriptions of identity by highlighting the integration of who one is with what one does.

Recognition by others and the significance of key narrators are repeatedly emphasized in studies with a discursive identity definition (e.g., Chen & Mensah, 2022; Danielsson & Warwick, 2014; Madden & Wiebe, 2015; Saka et al., 2013). For instance, Danielsson and Warwick (2014), without an explicit definition of teacher identity, highlighted that an individual's identity can be defined both internally and externally by a group's inclusive or exclusive attitude towards that individual (Paechter, 2003). The authors further elaborated:

If language, action, interaction, values, beliefs, symbols, objects, tools, and places are put together in such a way that others recognize a person as a particular type of 'who' engaged in a particular type of 'what,' then they can be seen to be both enacting a particular Discourse and representing a particular facet of their professional identity. (Danielsson & Warwick, 2014, p. 291)

In this way, the authors underscored that recognition is a crucial link between discourse and identity.

With discursive identity, significant individuals ascribing this recognition are emphasized. For example, professors, peers, supervisors, cooperating teachers, and colleagues have a major role to play in the identity building that goes with participation in the experiences that student teachers encounter. Danielsson and Warwick (2014) noted that these significant individuals had influence on the Discourses in which the student teachers engaged and their eventual qualification (or lack of qualification) as a teacher. Chen and Mensah (2022) pointed

out that for Teachers of Color, an integral part of one's identity lies in how and by whom they are recognized as science teachers. Consequently, affirmative recognition as a science teacher by significant narrators, such as members of the CoP with the most influential voices (Sfard & Prusak, 2005), has a substantial impact on the development of one's science teacher identity.

Finally, studies with discursive identity definitions typically involve examining the development, transformation, and multiple dimensions of science teacher identity (e.g., Avraamidou, 2014b; Carrier et al., 2017; Madden & Wiebe, 2015; Naidoo, 2017; Purwaningsih et al., 2020). They also explore contextual factors contributing to identity development (e.g., Khoza, 2022; Luehmann, 2008b; Luehmann & Tinelli, 2008; Marco-Bujosa et al., 2020; Saka et al., 2013; Wei et al., 2021).

Performative identity

Studies utilizing the performative identity definition concentrate on the positional identity of science teachers on the one hand, which relates to the social roles and positions an individual occupies, and the abilities displayed by teachers on the other. These studies show that science teacher identity is influenced by personal achievements and competence within a specific domain. Only three articles in our review explicitly employed this type of definition. Both Rivera Maulucci (2013) and Moore (2008b) used positional identity to represent science teacher identity. The operational definition of positional identity was derived from the relative positionalities of the teachers, such as their race, ethnicity, class, gender, age, and religion, among many others, allowing individuals to acquire knowledge of science and themselves and to define themselves in unique ways. The concept foregrounds the ways larger structures, such as social constructions of race, gender, and class, frame the ways individuals position themselves and are positioned within particular social contexts, such as the school or family (Moore, 2008b). The two articles stressed that individuals performed as teachers with combined multiple identities, and the idea of positional identity is important in understanding the role of agency and passivity in the development of science teacher identity.

Summary of findings

In summary, studies with different categories of definitions emphasized different aspects of science teacher identity and identity development. Performative identity emphasizes the active performance and enactment of identity, whereas narrative identity concentrates on the construction of identity through narration and life narratives. Discursive identity emphasizes the function of language and discourse in identity construction,

while participative identity emphasizes identity within a particular context or activity. Discursive identity definitions emphasize the influence of power, ideology, and dominant discourses on identity construction, whereas narrative identity emphasizes the importance of coherence and continuity in constructing one's life story. Participative identity emphasizes the role, membership, and involvement in a particular context, whereas other concepts emphasize identity construction and negotiation more broadly.

However, studies employing different categories of definition also share common characteristics. All studies acknowledge that science teacher identity is not static but is constructed and shaped through various processes. They also acknowledge that science teacher identity formation and development are shaped in part by their sociocultural and contextual experiences. They all highlight the active role of individuals in the construction, negotiation, and presentation of their identities while recognizing the importance of social interactions, relationships, and the meaning-making process in shaping identity.

Research question 4: major research findings on science teacher identity

In this section, we present the major findings on science teacher identity. First, we present a table that represents the categories of science teacher identity research questions: identity process or development, identity factors, and identity nature. In the sections that follow, we discuss the major study findings according to themes within these categories of research studies.

Table 4 presents the classification of 48 studies, among which 31 are in the category of identity process or development, 15 are in the category of identity factors, and 2 are in the category of identity nature (see Table 4).

Identity process or development

Studies on science teacher identity development or process covered different teaching stages of the teacher's career, including 16 studies with preservice teachers, 9 studies with in-service teachers, and 7 studies with both preservice and in-service teachers. Four major themes characterized findings from these studies: (1) significance of experiences or stories for science teacher identity formation; (2) development of social justice and equity-oriented science teacher identity; (3) science teacher identity development in specific contexts; and (4) transitions and tensions among science teachers' multiple identities.

Theme 1: Significance of experiences or stories for science teacher identity formation

Avraamidou's series of studies and other studies influenced by these studies had findings situated within this

Table 4 Science teacher identity study categories based on research questions

Study category	Articles
Identity process or development	Avraamidou (2014b, 2016b, c, 2019), Akerson et al. (2014), Carrier et al. (2017), Chen and Mensah (2022), Coddington and Swanson (2019), Danielson and Warwick (2014), Danielowich (2012), Edwards and Edwards (2017), Forbes and Davis (2008), Hathcock et al. (2020), Ibourk (2021), Katz et al. (2011) Marco-Bujosa et al. (2020), Moore (2008b), Munfaridah et al. (2022), Naidoo (2017), Olitsky (2020, 2021), Proweller and Mitchener (2004), Rivera Maulucc (2013), Saka et al. (2013), Shwartz and Dori (2020), Siry and Lara (2012), Varelas et al. (2005, 2023), Wei et al. (2021), Wilson and Deaney (2010), Wilson et al. (2015)
Identity factors	Allaire (2013), Blackmore et al. (2018), Dominguez et al. (2015), Eick and Reed (2002), Katz et al. (2013), Khoza (2022), Luehmann (2008a, b), Luehmann and Tinelli (2008), Madden and Wiebe (2015), Moore (2008a), Pérez Gracia et al. (2019), Purwaningsih et al. (2020), Upadhyay (2009), Woolhouse and Cochrane (2015)
Identity nature	Badia and Iglesias (2019), Silva et al. (2021)

theme (Avraamidou, 2014b, 2016b, c, 2019; Carrier et al., 2017; Ibourk, 2021). Each of these studies focused on preservice science teachers, particularly elementary preservice science teachers. The main aims of these studies were to trace or describe the sequential events and experiences that teacher candidates had over time in a variety of contexts, and to examine how these stories or experiences shaped the preservice science teachers' identities. These studies collected stories of teachers at different time points, including from their childhood outside of school, as a science learner at school, and during their teacher preparation programs as prospective teachers, which were nestled within different contexts, such as the home, school, and university. Various qualitative analytical frameworks were used to analyze the prominent experiences and stories, resulting in the following major findings on science teacher identity formation:

1. Teachers' life histories or experiences in relation to science shape their identities.
2. Teacher preparation programs are critical in shaping preservice science teachers' identities.
3. Emotional factors or affective domains associated with science experiences are also important for science teachers' identity development and redevelopment.
4. When teachers encounter negative experiences, their agency also plays a critical role in constructing their identities.

The above findings on science teacher identity development or process suggest that the nature of science teacher identity is situated, historical, relational, multi-dimensional, social, and contextual (Avraamidou, 2019; Ibourk, 2021). Some limiting factors such as traditional schooling and stereotypical images of scientists (Carrier et al., 2017), as well as driving factors, like exposure to reform-minded strategies and understandings about science teaching (Avraamidou, 2014b), were also identified.

Studies focusing on identity development or process also examined how specific or certain experiences contribute to the development of science teacher identity. For instance, Naidoo (2017) explored the ways science teacher identity was influenced by experiences in a science methods course. Hathcock et al. (2020) focused on science teacher experiences during a professional development project, whereas Siry and Lara (2012) did so during a collaborative field-based course. In addition, Moore (2008b) highlighted the roles of reflection and positionality in the identity formation process. These studies reached the following main conclusions:

1. Science teacher identity development is an ongoing process of producing, reproducing, and transforming.
2. The frictions or tensions between teachers' existing identities and new identity components are opportunities for their identity change or transformation.
3. Social practice—such as participation in professional development projects, field work, and reflection—leads to identity transformation.
4. Prior beliefs and epistemological perspectives are important resources for science teachers to develop their science teacher identities.

Theme 2: Development of social justice and equity-oriented science teacher identity

Studies in this theme involved a specific group of science teachers, such as Teachers of Color, in a specific context, such as urban schools. The focus was on how science teachers developed identity and agency with social justice orientations to challenge and transform the constraining structures within their contexts. For example, Chen and Mensah (2022) examined the ways two elementary science Teachers of Color developed their identities as they participated in science professional development and how they individually and collectively engaged their agency to prioritize science within and against the structural constraints that marginalized science in their schools. Varelas et al. (2023) explored how new science Teachers of Color in urban schools embraced equity and excellence in various ways as their science teacher

identities were shaped and reshaped while learning to teach. Both Olitsky (2020) and Rivera Maulucci (2013) examined the role of emotions in forming science teacher identities, with a commitment to social justice and equity. Olitsky (2021) highlighted the important mediating role of internal conversations by which science and math teachers in high-needs urban schools developed a sense of professional identity, agency, and group membership in the context of instructional reform. The major findings of studies in this theme were:

1. Science teachers' multiple identities and histories of larger institutions and structures (e.g., science, schooling, and society) are intertwined, providing the background for science teacher identity development with social justice and equity orientations towards science and science teaching.
2. In seeking social justice and equity orientations towards science and science teaching, science teachers may experience identity conflicts.
3. The dialectical relationship between structure and agency is an integral part of science teacher identity construction.
4. Some strategies, such as legitimate science knowledge production and the design of science professional development, are effective in enabling teachers to enact their agency to develop their science teacher identities.
5. Emotions and self-talk play integral roles in science teacher identity for social justice and equity.

Theme 3: Science teacher identity development in specific contexts

Studies within this third theme examined science teacher identity development in specific contexts. For example, Munfaridah et al. (2022) examined the development of preservice physics teachers' physics identities through a specially designed course that incorporated multiple representations, such as pictures, diagrams, equations, and verbal reasoning, during problem-based lessons in Indonesia. Wei et al. (2021) explored how the constraints of the school context and one's personal dispositions, such as approach to practical work, influenced a beginning physics teacher's identity development during the first 2 years of his teaching career in China. In the U.S., Coddington and Swanson (2019) explored the influence of various classroom contexts and early field experiences on preservice teachers' identity development and future career decisions. Also in the U.S., Katz et al. (2011) investigated whether an experience in an out-of-school context, an afterschool science education program, could develop teacher candidates' professional identities in

ways that complement and enhance their identity development from experiences in formal school settings. The major findings of studies in this theme are:

1. Context impacts science teacher identity formation.
2. Practical experience is integral to the formation of a science teacher's identity.
3. Prior experiences impact science teacher identity.
4. Learning in various internship placements is a process of constructing science teacher identity.
5. Interaction with others, such as teacher colleagues, students, and curriculum materials, is an important means to develop science teacher identity.
6. Self-reflection is also essential for identity development.
7. Internship programs, whether in- or out-of-school, afford preservice science teachers the opportunity and space to compare their personal identities to standard, model, or ideal identities.

Theme 4: Transitions and tensions among science teachers' multiple identities

Studies within the fourth theme had two distinct foci: the transformation of science teacher identity and the negotiation of multiple identities. Studies identified various ways to promote the transformation of other identities into a science teacher identity (Akerson et al., 2014; Proweller & Mitchener, 2004; Schwartz & Dori, 2020; Wilson & Deaney, 2010). For example, in Israel, Schwartz and Dori (2020) showed which identity resources could be perceived as supportive in the identity transformation process from chemistry scientists to chemistry teachers. In the U.S., Akerson et al. (2014) explored the development of professional identity as a teacher of the nature of science (NOS) from a university science methods course professor to an elementary science teacher. Wilson and Deaney (2010) focused on how a science teacher in the United Kingdom stepped away from a previous career as a biochemical engineering program manager to be a science teacher and ultimately resigned from her first teaching post. The major findings of these studies were:

1. The development of science teacher identity is influenced both by personal and contextual factors.
2. The transformation of science teacher identity is an ongoing interpretation and reinterpretation process that involves agency to drive identity changes.
3. The social construction of role identity in work contexts is about acting out an expected science teacher role, including self-verification, and being recognized by others as a professional teacher.

4. Identity transformation requires supportive resources and contexts, such as science coursework and field experiences.
5. A previous career is an essential part of TPI. There are competing identities, and teachers resolve identity conflicts through prioritizing different identities.
6. The desire to contribute to society and future visions as science teachers foster TPI transitions.

Studies in this fourth theme also examined the negotiation of multiple identities. For example, Marco-Bujosa et al. (2020) explored how the context of a bilingual elementary school for students who are Deaf in the U.S. influenced the science teaching identity of one elementary classroom teacher as she transitioned to the role of science specialist. In New Zealand, Edwards and Edwards (2017) explored the identity formation of a science teacher who was embedded in two cultures simultaneously, that of indigenous Māori and English. Varelas et al. (2005) explored how beginning teachers, in the U.S., are immersed in science as both scientists and science teachers. The major findings of these studies are:

1. Teachers may experience conflict among different identities, and these various identities need to be reconciled or negotiated.
2. Collaboration and social interaction influence teacher identity formation.
3. Personal histories contribute to science teacher identity formation.

Identity factors

Among the 15 studies with an emphasis on identity factors, 8 involved preservice teachers, and 7 involved in-service teachers. For preservice science teacher identity, the following were major study findings:

1. Subject matter knowledge and subject-specific pedagogy knowledge benefit preservice science teacher identity development.
2. The nature or characteristics of teaching preparation programs, including formal and informal contexts, are important factors impacting science teacher identity.
3. Preservice science teachers' identity development is furthered through engaged working and learning with peers, network formation, interpersonal relationships, and participation in reflexive discussions.
4. Impact factors include belonging in a community and valuing science as a subject, along with teachers' affinities related to science and their gender identities.

For in-service teachers, Luehmann (2008a, b) and Luehmann and Tinelli (2008) found that science teacher identity was impacted by teachers' self-narratives and confirmation of these narratives by others. The multiple identities of racially and culturally minoritized in-service teachers (Allaire, 2013; Upadhyay, 2009) and external tensions, such as high-stakes testing environments (Upadhyay, 2009) in the U.S., also impacted identity development.

Identity nature

Two studies focused on the nature of identity. In Chile, Silva et al. (2021) analyzed the continuing education experiences of teachers participating in a summer camp and the effects of this experience on TPI. The study identified two dimensions of TPI, personal and contextual, in teachers' reflective journal narratives. Specifically, the personal dimension of TPI had more categories than the contextual dimension of TPI and included self-perception (which can play both negative and positive roles), self-definition as a teacher, and the significance of their role in the education community. The contextual dimension included professional teaching performance and the difficulties of working in adverse political or institutional settings.

The Badia and Iglesias (2019) study had two aims: to understand the relationship among different components of identity, and to describe types of science teacher identities. Based on a survey conducted with 104 high school science teachers in Utah, U.S., there were strong correlations among teachers' conceptions of teaching and learning, conceptions of NOS, feelings about technology, competency in using technology, and frequency of classroom technology use. Specifically, through a hierarchical cluster analysis, three clusters of teacher identity were identified: agreeing with constructivism-disagreeing with instructivism, strongly agreeing with constructivism-strongly disagreeing with instructivism, and strongly agreeing with constructivism-undecided about instructivism. Badia and Iglesias concluded that studying science teacher identity using various interrelated components is a more powerful way of understanding science teachers and their science teaching than focusing solely on one component.

Discussion

In Avraamidou's (2014a) review of research on science teacher identity, several areas for future research were identified. In the following discussion, we reflect on the progress made in these areas and the questions that remain open.

Studying science teacher identity as a process

As Avraamidou (2014a) pointed out, it is important to view teacher identity as a dynamic, evolving construct and focus on teacher identity formation and development. Over the past two decades, many studies have focused on the development of science teacher identity. Among the 48 articles reviewed in this study, 31 were concerned with the identity development process, with 20 of them published after 2013. With the goal of establishing a common understanding about the process, studies have examined factors, variables, contexts, and experiences that impact science teacher identity development.

The findings of these studies shed light on several key aspects: first, teachers' experiences or stories, such as those of their teacher preparation programs, practical experiences, previous careers, life histories in relation to science, and affective domains associated with science experiences, are critical in shaping science teachers' identities. That is, they should be viewed as important assets to be leveraged in opportunities for science teacher identity development. Second, learning, participation, and interactions with others in communities are part of the process of constructing science teacher identity. Third, the formation of science teacher identity is a process of agency; it is an ongoing interpretation and reinterpretation process.

Theoretical frameworks of identity

In this section, we respond to Avraamidou's (2014a) critical inquiry: "*What theoretical frameworks and what theories of identity are most appropriate in educational research, and specifically in science education?*" (pp. 166–167, emphasis in original), but in relation to theoretical frameworks used in the science teacher identity studies reviewed. Studies with explicit theoretical frameworks have referenced Lave and Wenger's (1991) situated learning and Wenger's (1998) CoP theories, Gee's (2000) sociocultural theory, Holland et al.'s (1998) identity and agency in cultural, figured worlds theory, and social psychology theories of identity that have sociological underpinnings (e.g., Kagan, 1992; Stryker & Burke, 2000; Stryker & Serpe, 1994). By considering the interplay among contexts, environments, personal values, behaviors, beliefs, social interactions, these frameworks are useful for understanding the complexities of identity formation.

Nevertheless, our review reveals the need for clarity in theoretical frameworks, which entails explicit mention and precise descriptions of these frameworks, constructs, and relationships among the constructs, in studies of science teacher identity. Although science teacher identity

is unique from general teacher identity or teacher identity of other subjects (Feser & Haak, 2023), there is a need for theoretical frameworks of science teacher identity to make these distinctions, particularly regarding which aspects align with or diverge from general TPI. Currently, science teacher identity studies build from theories of identity in general or TPI. There is a need for studies to consider what aspects are unique to theories of science teacher identity and to use their empirical findings to contribute towards elaborations of the theoretical frameworks in more nuanced ways. Thus, we wonder, what intricacies might emerge from theorizing and studying disciplinary or interdisciplinary science teacher identities, including biology or STEM teacher identities, as well as the relationships of science teachers' science identities or math identities in relation to their general science teacher identities or disciplinary science teacher identities, as in biology or physics? Suarez and McGrath (2022) argue that there is a gap in how collective TPI can be developed and strengthened, to allow certain communities to have greater identification and feelings of belonging, and in this sense, future theoretical framings should also consider how personal identities are related to a collective science teacher identity.

Though we agree that science teacher identity should be viewed as a process, we also push back against dichotomous lenses that see science teacher identity as only a process or only an attribute, and that only one of the two can be true. As with Wenger (1998), we recognize that identity is "not merely a category, a personality trait, a role, or a label" (p. 163). Yet, we believe science teacher identity can be conceptualized as both a process and can also be considered as an outcome in a particular moment in time, much like Darragh (2016) who frames this interpretation as putting on a bifocal lens as she asks, "Can we combine the action and acquisition views of identity?" (p. 28). In these ways, process and product views of science teacher identity do not need to be in contradiction.

Moreover, the overarching focus in the theoretical frameworks in science teacher identity studies remains on the individual science teacher and their agency, which are important. However, we believe that more attention can be paid to the interplay of agency in relation to these structures, without neglecting structure. This emphasis, which is also common in studies of students' science identities (Danielsson et al., 2023; Shanahan, 2009), speaks in part to other arguments on the need to attend to group level processes, memberships, and affinities and their roles in relation to the individual identities of science teachers (Rushton & Reiss, 2021). Yet, it is important to go beyond only social groupings and affinities to explore the historical, political, economic, and sociocultural contexts, and for theoretical frameworks to attend

to micro-, meso-, and macro-levels and the relations among them.

Currently, frameworks emphasize the micro-level, with less attention towards their relationships with the meso- and macro-levels. More exploration is needed to explain how these macro-structures are formed and develop over time, recognizing that society and what it means to teach will also shift across time scales and places. As Burke and Stets (2023) state, future studies "can utilize the full integration of the theory to better understand the nature of the links between society and the individual, and between the social structure and the self, including all its contained identities" (p. 238). Frameworks should consider how person identities are related to role and group identities, which in turn are "nested within broader social structures such as the structural divisions in society, for example, gender and racial/ethnic divisions," and these frameworks should attend to "prestige, power, and resources," which contribute to the stratification of society (Burke & Stets, 2023, p. 242).

Such lenses are important to move beyond only teachers responding to and navigating various tensions as they manifest at the individual and local levels, to exploring how individual teacher actions and performances, in connection with other educational system stakeholders, either transform or reproduce these structures at different levels, including norms, expectations, and policies for the science teaching profession. As Shanahan (2009) remarks, "There is yet to be broad attention to the actions of students, teachers, parents, and administrators that create and make these real norms. We understand that these norms exist but have not thoroughly explored how and why they emerge" (p. 61). With renewed attention to articulating each of these levels in theoretical frameworks, onus is not solely centered on science teachers. Instead, responsibility is distributed across the education system to not only create supportive mechanisms that promote science teacher agency and autonomy but to also redesign more just, equitable education systems and societies that allow science teachers to authentically enact reform-oriented beliefs without conflict.

Reflecting on the theoretical frameworks of the reviewed studies underscored for us how imperative it is for researchers to revisit the original texts of the theoretical frameworks, which they cite and use in their studies. As Stets et al., (2020) remark, to apply the "tools and techniques" of identity theory or any theory "requires a full understanding of the whole theory—its background, its development, and what it is attempting to explain," because a theory "has a perspective" and is "more than just a set of definitions, propositions, and scope conditions" (pp. 209–210). In essence, when the "whole of a theory is not examined, it makes interpretations even

more precarious. This halts scientific progress for the research community” (Stets et al., 2020, p. 210).

Researchers need to revisit these theories in full to recognize how some aspects are underutilized or misunderstood. For example, Gee (2000) recognized the socially constructed nature of race and gender, such that they should not be considered in essentialist or reductionist ways as they sometimes are when interpreted as static, genetic categories of Nature-Identities; the social construction framing has potential for exploring the nuances of science teacher identities of Teachers of Color and gender-minoritized teachers in various contexts. For studying identities and positioning, researchers can move beyond Holland et al. (1998), to reviewing some of the positioning theory work, whom they cite, of Harré, Davies, and Van Langenhove; doing so will reveal more complexities in structures shaping positioning and more types of positioning that can be useful for conceptualizing science teacher identity. Wenger (1998) offers different learning and identity trajectories, such as peripheral, inbound, insider, and boundary, considers the “nexus of multimembership” and “reconciliation” (p. 158), and the local–global interplay, yet these aspects of CoP are underexplored in the extant science teacher identity literature. While mentioning cultural-historical activity theory (CHAT), which like Shanahan (2009), we view is a fruitful theoretical framework for use in future studies due to its ability to connect multiple levels of analysis, Naidoo (2017) did not reference Cole, Engeström, Leontiev, and Vygotsky, whose work contributed to CHAT, nor attend to the subject, object, rules, community, and division of labor components of the theory. Overall, researchers should more fully explore the theoretical frameworks they cite to recognize and utilize their full affordances, and should explore identity theories in other disciplinary traditions, which might also reveal new insights.

Connecting science teacher identity research and reform recommendations

Some of the reviewed studies have addressed the intersection between science teacher identity and reform recommendations. For example, scientific inquiry emerged as a central component of science teacher identity (Avraamidou, 2014b). Research has identified various factors that contribute to reform-oriented practices and the construction of science teacher identity, such as cultural context, social support, the relationship between personal and institutional identities, exposure to reform strategies in action, engagement in structured inquiry during teacher preparation programs, participation in science content courses and science practices, diverse teaching and work experiences, PCK development,

learning orientations, past school experiences, social networks, and information technology (Carrier et al., 2017; Eick & Reed, 2002; Luehmann & Tinelli, 2008; Saka et al., 2013).

Beginning science teachers face challenges in the process of constructing their identities, including the close relationship between practical work and science inquiry, the accountability policies of educational institutions or governments, constraints imposed by textbooks and testing structures, as well as limited teaching time. They also experience tensions, such as conflicts between existing and desired professional selves, embracing elements of a “scientist identity,” integrating reform-oriented teaching practices into their identities, conflicting perceptions of science teaching, and the complexity of the teaching profession (Carrier et al., 2017; Danielowich, 2012; Katz et al., 2011; Wei et al., 2021). For in-service science teachers, Olitsky (2021) suggested that promoting teacher autonomy and providing support can help foster their reform-minded identities in practice.

Several reviewed studies focused on social justice and equity-oriented reform agendas. Notably, significant attention is devoted to the experiences of racially/ethnically and gender minoritized teachers in this category of research, acknowledging the distinctive challenges and opportunities they encounter throughout their professional journeys. This body of research explores the experiences of Teachers of Color, in teaching contexts rife with tensions and contradictions, and their navigation of the complex interplay between structures and agency. These studies have examined the multifaceted processes by which Teachers of Color construct their science teacher identities and strive for social justice and equity (Chen & Mensah, 2022; Moore, 2008a; Olitsky, 2020; Varelas et al., 2023), thereby revealing the complex interaction of personal experiences, social interactions, and systemic factors that influence science teacher identity formation.

Despite the progress made, there is still a significant need for further research on the construction of science teacher identity associated with more recent reforms, such as the implementation of the *Next Generation of Science Standards* (NRC, 2013) in the U.S. and the rise of global STEM education reform movements (Liu & Wang, 2023; NRC, 2014), while recognizing that these reform contexts have changed and will continue to change over time. What it means to be a “reform-minded science teacher” will vary across and within cultures and countries, over time, space, and place, and these nuances must also be considered. Thus, it is necessary to not only address the challenges faced by preservice and in-service teachers in constructing their identities within the contexts of these recent science education reforms but also

to examine the dynamics and resolutions in developing their science teacher identities over time, throughout waves of reform, that might carry different meanings across stakeholders and education systems with various priorities. Notably, science teacher identity of veteran science teachers, in relation to these reforms in particular, is an area in need of further exploration. These studies will offer insights into effective strategies for retaining science teachers and facilitating the cultivation of their reform-oriented identities across longitudinal trajectories.

Conducting large-scale, longitudinal, and life-history studies

Several studies used longitudinal, ethnographic methods to investigate science teacher identity trajectories (Avraamidou, 2014b, 2016b, c, 2019; Munfaridah et al., 2022; Wei et al., 2021). These studies identified key factors, such as teachers' life histories in relation to science; engagement in scientific inquiry teaching or fieldwork; relationships with family members, instructors, and fellow teachers; and considerations of gender, desires, and emotions related to science. In addition, teacher preparation programs, classroom environments, and pre-existing identities play crucial roles in shaping science teacher identity development (Avraamidou, 2014b, 2016b, c, 2019). These studies affirm the situated, historical, relational, and multidimensional nature of science teacher identity and discuss how various sub-identities influence it. The relationships between science teacher identity and other identities, such as teachers' science, personal, and collective identities, deserve more research as well.

Several studies collected longitudinal data to capture the process of science teacher identity development and formation (Chen & Mensah, 2022; Ibourk, 2021; Olitsky, 2020, 2021; Proweller & Mitchener, 2004; Saka et al., 2013; Varelas et al., 2005). These studies tracked participants through interviews, written reflections, field notes, questionnaires, and other means. Collectively, these studies provide valuable insights into the complex process of science teacher identity development and highlight the significance of various factors and contexts in this process. Future longitudinal studies can follow science teachers throughout their preservice teacher education, induction, and remainder of their careers, to extend beyond these previous longitudinal studies, which span no more than 4 years.

The majority of longitudinal and life-history studies involved qualitative research designs with relatively small samples. There is still a scarcity of large-scale, quantitative research studies that track the long-term development and shifts in science teacher identity as well as the factors that influence this process. More research is needed to address this gap. For example, it is necessary

to conduct large-scale, longitudinal studies that measure the sustained effects of initiatives aimed at promoting and sustaining science teacher identity development. In order to do this, valid, reliable, and fair measurement instruments are needed. Prior to the development of such instruments, clear conceptualizations and definitions of science teacher identity are necessary, which currently remain unavailable. As our scoping review demonstrated, there remains much ambiguity in studies of science teacher identity, with implicit theoretical frameworks and definitions of science teacher identity. While science teacher identity is indubitably a complex construct, our review results usher a clarion call for identity researchers to be explicit in stating their theoretical frameworks and definitions of science teacher identity and to ensure more coherence and consistency in employment of these lenses and terms throughout their studies. Future research should help define and map the domains and characteristics of science teacher identity and how they relate to each other.

Examining teacher identity enactment in school classrooms

Studies have examined science teacher identity enactment in school classrooms, such as from NOS (Akerson et al., 2014), curriculum (Forbes & Davis, 2008), and the dual roles of science teacher and scientist (Varelas et al., 2005) perspectives. Furthermore, researchers have identified factors influencing science teachers' entry into teaching, particularly for preservice teachers (Madden & Wiebe, 2015; Munfaridah et al., 2022). With a focus on novice teachers, these studies add to the existing literature on the interplay between the construction of science teacher identity and its connection to practice, as highlighted by Avraamidou (2014a). In addition, attention has been given to the constraints encountered during the process of science teacher identity development and transformation in the classroom (Chen & Mensah, 2022; Saka et al., 2013; Upadhyay, 2009).

Studies have suggested that conceptions, personal philosophies, and strategies of science teaching should be considered components of science teacher identity (Akerson et al., 2014; Avraamidou, 2019; Badia & Iglesias, 2019). By examining the interaction between science teacher identity and science teaching, these studies revealed multiple factors at the individual level contributing to the construction and transformation of science teacher identity in practical contexts, such as a teacher's other identities and personal characteristics, prior experiences, ongoing interpretation of practical work experiences, sense of agency, collaboration with others, group affiliations, and accompanying emotions (Akerson et al., 2014; Allaire, 2013; Avraamidou, 2016b;

Carrier et al., 2017; Coddington & Swanson, 2019; Hathcock et al., 2020; Marco-Bujosa et al., 2020; Munfaridah et al., 2022; Saka et al., 2013; Siry & Lara, 2012; Wei et al., 2021; Wilson et al., 2015).

Simultaneously, science teacher identity also affects science teaching. Teachers' identities as science teachers influence how and why they teach science and shape the relationships they develop with students (Madden & Wiebe, 2015; Moore, 2008b). In enacting science teacher identity, negative factors have been identified, including conflicting images of imagined and actual science teaching; dissonance between normative identity and personal identity; and ineffective, marginalizing experiences contributing to professional dissatisfaction, emotional exhaustion, and identity isolation (Carrier et al., 2017; Coddington & Swanson, 2019; Marco-Bujosa et al., 2020; Saka et al., 2013).

Significant institutional or contextual factors, that either facilitate or impede the construction and transformation of science teacher identity in practical contexts, include recognition from others and institutions, discourses from other key individuals, and the cultural context and contextual constraints surrounding science instruction (Carrier et al., 2017; Chen & Mensah, 2022; Proweller & Mitchener, 2004; Saka et al., 2013; Siry & Lara, 2012; Upadhyay, 2009; Wei et al., 2021). Factors that impose constraints on science teacher identity construction and transformation include schools prioritizing high-stakes testing as the predominant measure of teacher and student success, the devaluation of activity-based and participatory science teaching approaches, and the challenges faced by science teachers working in schooling systems that marginalize high quality science teaching for students of color by catering to high-stakes accountability and testing pressures (Chen & Mensah, 2022; Saka et al., 2013; Upadhyay, 2009).

Factors facilitating the formation and evolution of science teacher identity include engaging in effective self-talk, actively participating in reflexive practices within the classroom context, cultivating a cultural identity and acquiring relevant school-based knowledge, fostering a critical lens highlighting social justice, the presence of social support systems, and expanded agency and autonomy of science teachers (Olitsky, 2021; Proweller & Mitchener, 2004; Saka et al., 2013; Siry & Lara, 2012; Wei et al., 2021). These factors collectively portray the complex, multifaceted process of science teacher identity development and transformation. It is within this dynamic ecosystem of teaching practice, where macro-, meso-, and micro-level factors interact and influence each other, that the construction and transformation of science teacher identity occur.

Much progress has been made in examining the enactment of science teacher identity within school classrooms. However, further investigations and expansion of this research focus are still warranted. While we found that more studies utilized observations in addition to interviews, these studies were in the minority, and often relied only on several planned observations of science instruction. Though these observations are important towards understanding science teaching enactment, they mainly offer snapshots of science teacher identity in process; there is a need for more ethnographic, extended observations and job shadowing that follow teachers throughout the academic year and across years and contexts. For example, we still need to know more about how science teachers embody their identities when they engage with different students in different learning contexts, such as teaching different science and STEM courses and after school science clubs, across their teaching careers. This examination can help elucidate the intricate dynamics of science teacher identity development, as well as similarities and differences of these dynamics across various classroom contexts. Similarly, the influence of various forms of science educator practice—such as coaching, advising, tutoring, mentorship, and teacher leadership—on shaping and transforming science teacher identity also necessitates further examination. Collectively, these studies would surface day-to-day nuances and complexities that are largely missing from the extant science teacher identity research base.

Understanding the role of various contexts on identity development

Extensive research has been conducted to explore the influence of specific contexts and their affordances and constraints on the development of science teacher identity. Studies have examined various contexts and science teacher identity development, including the formal school system (Blackmore et al., 2018; Coddington & Swanson, 2019; Danielsson & Warwick, 2014), teacher preparation and training programs, discipline courses, internship programs (Blackmore et al., 2018; Carrier et al., 2017; Chen & Mensah, 2022; Woolhouse & Cochrane, 2015), different cultural contexts (Edwards & Edwards, 2017), urban schools in the U.S. (Varelas et al., 2023), and high-stakes testing environments (Upadhyay, 2009). These studies have produced valuable insights into the influence of different contexts on the development of science teacher identity.

The personal experiences of individuals as learners within the school system have a significant impact on their science teacher identity development (Blackmore et al., 2018; Danielsson & Warwick, 2014; Marco-Bujosa et al., 2020). Various training programs and courses

provide opportunities for science teachers to explore and develop their identities. Essential factors fostering the development of science teacher identity include enhancing subject area knowledge and pedagogy, developing professional reflective practices, cultivating a sense of belonging with peers in a professional community, encouraging discussion, negotiating new policies, adopting professional language and practices, and observing other teachers (Blackmore et al., 2018; Carrier et al., 2017; Chen & Mensah, 2022; Danielsson & Warwick, 2014; Munfaridah et al., 2022; Proweller & Mitchener, 2004; Siry & Lara, 2012; Varelas et al., 2005; Wilson et al., 2015; Woolhouse & Cochrane, 2015).

Identities develop and manifest to different extents in different contexts. The interplay of multiple identities within individuals can potentially lead to conflicts or mutual reinforcement, and the prominence of a particular identity is influenced by the sociocultural contexts in which they are embedded (Allaire, 2013; Edwards & Edwards, 2017). In addition, specific contexts, such as urban schools serving predominantly minoritized students in the U.S. often introduce additional tensions in the construction of science teacher identities, as teachers try to enact their reform-oriented, moral visions of science teaching amidst the realities of testing and accountability pressures that counteract and narrow these ambitions and efforts (Saka et al., 2013). The interaction of personal agency, values, and beliefs are integral components of science teacher identity construction (Upadhyay, 2009; Varelas et al., 2023). While we advocate for efforts to support science teacher agency, through supportive buffers from marginalizing experiences, we recognize that this attention neither absolves us from a simultaneous, related responsibility to change inequitable systemic conditions under which science teachers teach, that create the need for these support systems to help teachers navigate the challenging contexts to remain in the profession. Thus, future designed-based research-practice partnerships should attend to designing supportive systems for science teachers that recognize their personal histories, characteristics, and identities as assets and opportunities for their science teacher identity formation and development.

Furthermore, several studies have investigated the role of informal science education, like afterschool informal science education internships (Katz et al., 2011, 2013), as well as science camps (Silva et al., 2021), in facilitating the development of schoolteachers' science teacher identities. Research has identified the significance of these experiences and relationships with families in shaping science teacher identity (Avraamidou, 2014b; Carrier et al., 2017). Juxtaposed against formal education contexts, however, there is a scarcity of studies investigating

the impacts of museums, family, and everyday life on science teacher identity development; more work can be done in this area (Adams & Gupta, 2017).

Conclusion

The objective of this scoping literature review was to identify pertinent empirical studies on science teacher identity to map out our current knowledge on this important research topic. Over the past two decades, there have been new insights into science teacher identity, related to the process of science teacher identity development, factors affecting science teacher identity formation and development, and the nature of science teacher identity. Although there are variations in the objectives, lenses, and methodologies employed across different studies, there is a strong consensus on the dynamic, complex, contextual, and process-oriented characteristics of science teacher identity, with various factors operating at different levels and influencing it.

However, our review's findings reveal the ambiguity and implicit approaches that dominate conceptualizations of science teacher identity, and the need for more precise, explicit theoretical frameworks and definitions in these studies. This work is a prerequisite for developing valid, reliable, and fair instruments for science teacher identity, which is a related gap. Given the continuously evolving nature of science teacher identity, developing valid, reliable, and fair instruments to capture the relatively stable facets of science teacher identity at a given moment in a given context would greatly facilitate large-scale, longitudinal studies of science teacher identity development. Our scoping review revealed a dearth of such instruments and studies that can use representative samples to make causal inferences, arguments, and conclusions about cross-country educational systems, to better support the development of education policies (Suarez & McGrath, 2022). Through this essential work to address these gaps, we envision more mixed-methods studies and cross-cultural, international collaborations that dovetail synergistically to strengthen and build from a rapidly growing reservoir of foundational science teacher identity research.

Abbreviations

ASC	Academic Search Complete
CoP	Communities of Practice
DSMRI	Dynamic Systems Model of Role Identity
EBSCO	Elton B. Stephens Company
ERIC	Education Resources Information Center
NOS	Nature of Science
OECD	Organisation for Economic Co-operation and Development
PCK	Pedagogical Content Knowledge
PRISMA–ScR	Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews
SIA	Social Identity Approach
STEM	Science, Technology, Engineering, Mathematics, and Medicine
TPI	Teacher Professional Identity

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s40594-024-00481-8>.

Additional file 1. List of 48 Reviewed Articles.

Acknowledgements

The authors would like to thank the editors and anonymous reviewers for their constructive feedback.

Author contributions

YFZ contributed to conducting literature searches, managing collected studies, screening, coding, and analyzing data, as well as taking responsibility for manuscript writing. JT was leading the revision of the article to address reviewers' concerns and suggestions. XFL was responsible for designing the study, creating the protocol and codebook, and guiding the manuscript preparation and revision. The final manuscript was read and approved by all authors.

Funding

This study was not supported by any internal or external funding sources.

Availability of data and materials

All supporting data generated or analyzed for this study are available upon request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

We affirm no competing interests financially or otherwise with this study.

Received: 11 September 2023 Accepted: 22 March 2024

Published online: 01 April 2024

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