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Enriching computing identity frameworks: integrating current constructs and unveiling new dimensions for today's tech-savvy world—a systematic review

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This systematic review seeks to improve the existing framework for developing students' Computing Identity (CI) by integrating contemporary elements and identifying new dimensions. A meticulous selection of 31 articles followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol, ensuring a comprehensive and systematic approach. The findings highlight factors that influence students' CI and also the constructs defining the frameworks for developing students' CI. The identified existing constructs are competence/performance, interest, sense of belonging, and recognition in computing, with competence/performance being the most explored and recognition the least. The review proposes a new framework for developing students' CI that includes the "social context" as it interweaves with existing constructs to shape the multifaceted process of CI formation. The findings underscore a research gap concerning the inclusion of diverse perspectives, which is essential for a richer understanding of CI. Additionally, the study emphasizes the potential to incorporate new elements to enhance the existing frameworks for developing students' CI, along with its validation in diverse contexts.

KEYWORDS

computing identity frameworks, computing identity, computing identity constructs, identity, systematic review

Introduction

A critical factor influencing enrollment and continuity in any academic field is students' disciplinary identity—how they perceive themselves within a specific discipline. This concept has garnered attention in academic discussions (Cribbs et al., 2015; Hazari et al., 2010). Identifying identity within a discipline plays a vital role in understanding students' self-perceptions, which significantly impact their learning, perseverance, and professional aspirations (Mahadeo et al., 2020). In today's tech-savvy world, the rising demand and appeal of computer science (CS) continue to grow significantly. In today's rapidly evolving digital landscape, possessing certain skills and competencies is essential for individuals to thrive in various domains. Tech-savvy pertains to a strong understanding and proficiency in utilizing technology effectively, such as navigating digital platforms, engaging with various digital tools, and leveraging technology to enhance productivity and efficiency (Yu et al., 2022). In the high-tech era, being tech-savvy is increasingly associated with perceptions of effective leadership, who can understand and harness the potential of emerging technologies, enabling them to make informed decisions and drive innovation (Nagpal et al., 2023). In this context, the development of a strong computing identity (CI) is crucial, particularly for underrepresented groups in CS and STEM fields. CI refers to an individual's sense of belonging and identification with the field of CS (Rodriguez and Lehman, 2017). Cultivating a positive CI can significantly influence one's academic persistence and commitment to pursuing a career in technology-related fields.

Scholars have considered CI as something individually possessed, constructed, or negotiated through interaction (Kinnunen et al., 2018). To comprehend how CI is developed, it is crucial to examine the framework for developing CI (referred to as CI framework). A widely acknowledged framework for developing students' CI comprises four key constructs: competence/performance, recognition, interest, and a sense of belonging (refer to Figure 1) (Taheri, 2019; Taheri et al., 2018). Various constructs within the CI framework are defined as follows. "Performance/Competence" pertains to a student's belief in their capacity to understand, execute, and achieve success in computing endeavors (Çakır et al., 2017). "Interest" signifies the level of passion, motivation, or curiosity that students hold toward computing and related fields. The "recognition" element relates to how students self-recognize and perceive others' opinions or viewpoints about their computing abilities (Çakır et al., 2017). "Sense of Belonging" refers to students' perceptions of their fittingness within the computing community. It involves feeling accepted, valued, and supported in the social environment associated with computing (Çakır et al., 2017; Boyer et al., 2010).

However, various studies have approached the development of these CI frameworks differently. For example, Mahadeo et al. (2020) proposed three CI constructs—belief in one's performance/competence, interest, and recognition in computing—to form a framework for developing students' CI. Their research demonstrated that a CI defined by these constructs significantly predicted students' choices of careers in CS-based fields (Mahadeo et al., 2020). In contrast, studies by Taheri (2019) and Taheri et al. (2018) encompassed a broader spectrum by including four CI constructs: belief in one's performance/competence, interest, sense of belonging, and recognition of persistence in CS-related fields. Washington et al. (2016) devised the Computer Science Cultural Attitude and Identity Survey (CSAIS) to evaluate students' attitudes and identity in CS, employing the elements of "confidence" and "interest". Similarly, the framework, used to prioritize K-12 computing curricular standards, was developed based on constructs such as technical excellence in CS, leadership, civic engagement and service, and community outreach

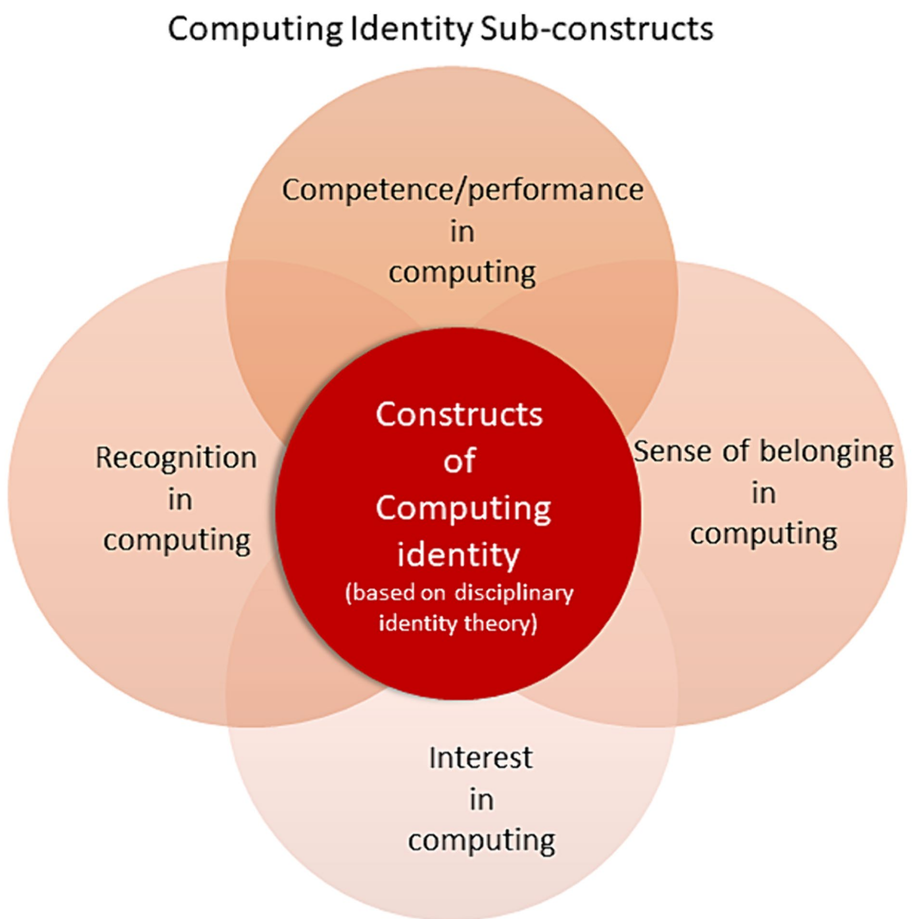

FIGURE 1
CI sub-constructs, including competence/performance, recognition, interest, and sense of belonging (5).

(Bell-Watkins et al., 2009). These differing approaches in constructing the framework for developing students' CI highlight the absence of consensus in conceptualizing and operationalizing CI constructs. Such differences in approach pave the way for a richer understanding of CI, by embracing diverse viewpoints and contributing to a dynamic landscape, aiming to formulate a comprehensive and universal framework. Although limited research has been conducted on CI frameworks, there has been considerable work on engineering identity, that could help gain a holistic overview (Capobianco et al., 2012; Mangu et al., 2015; Morelock, 2017; Patrick and Borrego, 2016). The engineering identity framework is often defined as a combination of cognitive, affective, and performance variables, which is significantly influenced by social context. According to Morelock (2017), engineering identity formation stems from related experiences, and environmental and social aspects. The perspectives on engineering identity frameworks solicited from students include their problem-solving ability, technical knowledge in math and science, creativity and innovation, communication and collaboration, integrity and ethics, and the positive social application of knowledge (Morelock, 2017).

The current review's theoretical foundation rests on the underpinning principles found in social-cognitive theories and disciplinary identity theories, which often form the core of CI research. Identity theories often intertwine with social theories, as students' identities and actions are influenced by their socially constructed environment, norms, regulations, and societal expectations. Previous studies investigating students' learning, retention, and persistence in CS have delved into various social determinants encompassing personal factors such as age, gender, nationality, family background, environmental factors related to school settings, and the support received from peers and teachers. Additionally, motivational factors like expectations and self-efficacy have been considered in these studies (Mangu et al., 2015; Bahar and Adiguzel, 2016; Dabney et al., 2013; Nugent et al., 2015; Sahin et al., 2015). Indeed, research on CIs frequently relies on a widely utilized framework among researchers to elucidate the processes involved in educational and career decision-making: Bandura's social cognitive career theory (SCCT) (Lent et al., 1994; Lent et al., 2000). SCCT stands as a popular theoretical model showcasing the influence of personal, environmental, and motivational factors on educational and career choices, as well as persistence and satisfaction within these domains. This theory emphasizes the substantial impact of these elements on individuals' choices and their levels of contentment within educational and career trajectories. While, identity theories outline how students' perceptions of their competence/performance, recognition, interest, and sense of belonging contribute to the formation of their identities (Taheri et al., 2018). When assessing the CI theory, the initial conceptualization has primarily focused on evaluating the degree to which students perceive themselves as individuals aligned with the identity of computer scientists or computing individuals (Taheri, 2019).

Despite extensive research focusing on identifying students' disciplinary identities in areas like STEM, science, engineering, and mathematics (Cribbs et al., 2015; Capobianco et al., 2012; Patrick and Borrego, 2016; Aschbacher et al., 2010; Kim et al., 2018), work is scarce in the realm of computing (Bell-Watkins et al., 2009; Smith et al., 2005; Galliher et al., 2017). Also, researchers have highlighted the need for an enhanced intersectional framework for developing CI, to support diversity and inclusion in the tech industry (Rodriguez and Lehman, 2017; Rodriguez et al., 2020). Thus, this systematic review aims to bridge this gap by comprehensively exploring all literature related to CI and its associated constructs. The research explores existing frameworks for developing students' CI, aiming to offer valuable insights into the current factors and potential new elements that contribute to fostering students' CI. The primary research questions (RQs) guiding this study are:

> *RQ 1*: What factors have been linked to CI development?
> *RQ 2*: What are the established constructs influencing/defining the frameworks for developing students' CI?
> *RQ 3*: What potential additions could further enrich these frameworks to align with the requisites of today's tech-savvy world?

Methodology

Search strategy

To comprehend the factors influencing CI formation, a systematic review has been conducted (Pantic and Clarke-Midura, 2019). For this, eligible research articles were consolidated using common web search engines such as "Web of Science," "Journals for Educational Research Information Center (ERIC)," and "Scopus." Specific keywords were included for searching the articles with explicit operators (AND or OR "*"), i.e., [("CI" OR computer science identity" OR "computational identity" OR "programming" OR "coding") AND ("framework" OR "identity") AND ("computer science" OR "IT" OR "ICT" OR "engineering" OR "information technology" OR "computer engineering")]. A systematic literature review technique aligning with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines was followed (Page et al., 2021). PRISMA is an evidence-based protocol for reporting in systematic reviews and meta-analyses.

Drawing on PRISMA methodology, the screening of relevant studies was executed in three stages (refer to Figure 2). In the initial search, a total of 985 papers were identified using the keyword search: Scopus ($n = 330$), ERIC ($n = 314$), and Web of Science ($n = 341$). Five hundred and forty-five articles were discarded due to duplication. Studies were selected through an initial review of titles and abstracts to gage relevance, followed by a rigorous examination of contextual alignment and sample description in adherence to inclusion and exclusion criteria. This methodical process ensured that only articles closely pertinent to computing identities and meeting predefined standards were included in the review.

Inclusion/exclusion criteria

The criteria used for article selection in this study were stringent and aimed at ensuring a focused exploration of computing identities within relevant disciplines such as computer science and IT. Included articles were restricted to those published in English up to January 2023, encompassing both journal articles and conference papers. Conversely, exclusion criteria were applied

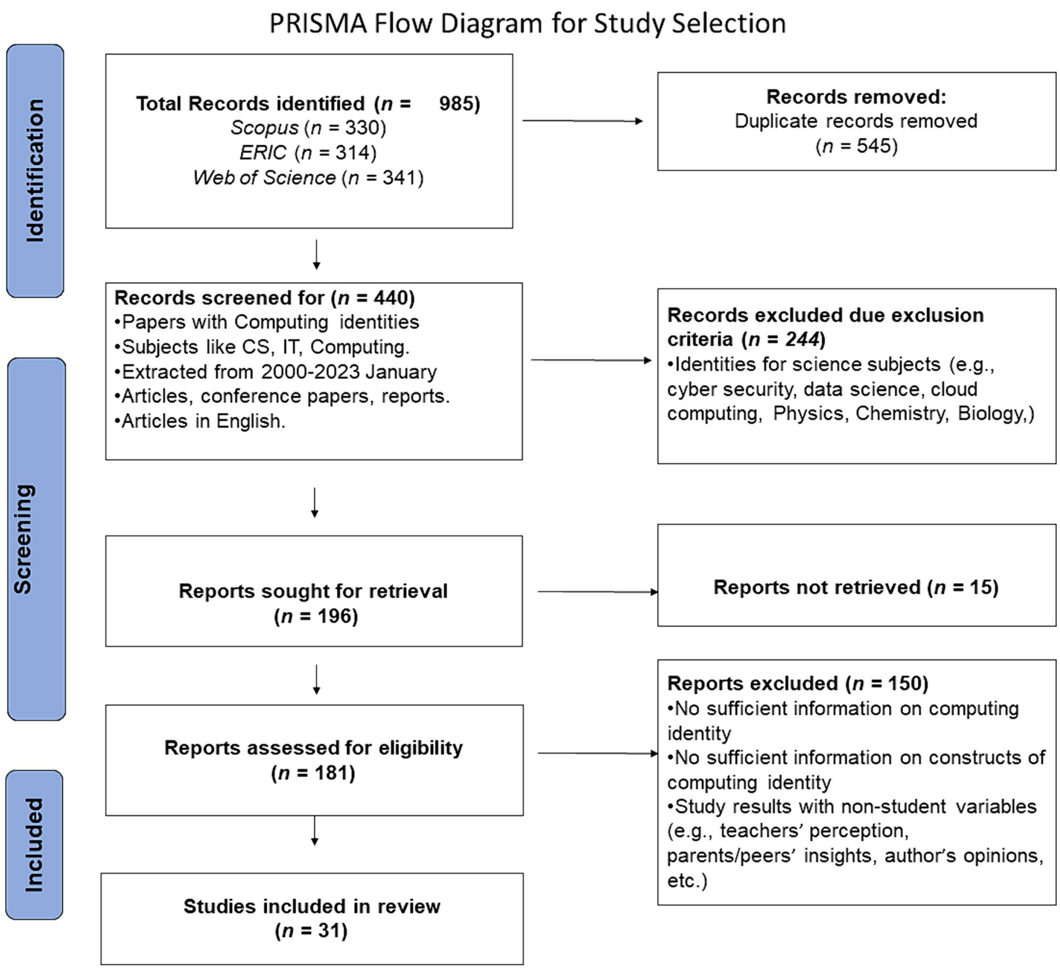

FIGURE 2
PRISMA 2020 flow diagram revealing the inclusion–exclusion criteria for studies included in the meta-analysis (28).

rigorously, excluding articles lacking comprehensive information on CI or its constituent constructs. Studies not centered on variables directly impacting students, such as opinions unsupported by empirical research or studies focusing on perspectives from teachers, parents, or peers, were also excluded. Additionally, posters, doctoral consortium articles, and publications shorter than two pages were deemed ineligible for inclusion. Adherence to the PRISMA methodology guided this thorough selection process, resulting in the inclusion of 31 meticulously chosen articles that met the study's exacting criteria (Figure 2).

Coding procedure

Two experienced authors with over 15 years of educational research background undertook the coding of the studies. Each paper was individually reviewed, and the data extraction process utilized the content analysis technique and subsequently, an interrater-reliability test was conducted to assess the level of agreement between the two coders. Cohen's kappa statistic was employed for inter-rater reliability analysis, yielding a value of 0.93, indicative of "almost perfect agreement." Any occasional discrepancies between the coders were addressed through discussions and consensus.

Shortlisted articles

Supplementary Figure S1 shows the number of articles shortlisted by (A) the type of document, (B) study design, (C) educational level, (D) year of publication, and (E) country of publication. Supplementary Figure S1A demonstrates an almost equal proportion of peer-reviewed and conference articles selected in our review (refer to Supplementary material). Most articles employed a quantitative research design (Supplementary Figure S1B). Most of the articles incorporated participants at the school level ($n = 20$) (Supplementary Figure S1C). The maximum number of relevant articles were published in 2018, 2019, 2021, and 2022, revealing that CI is an underexplored and emerging field of research (Supplementary Figure S1D). Finally, Supplementary Figure S1E shows that most studies were conducted in the U.S.A. ($n = 19$), followed by Hong Kong ($n = 3$).

Supplementary Table S1 illustrates the descriptive features of the 31 studies shortlisted for the review: (a) Studies, (b) study design, (c) participants, (d) CI constructs, (e) CI sub-constructs, (f) study results, and (g) country of publication (refer to Supplementary material).

Results and discussion

CI is an important predictor of students' enrollment, persistence, retention, and career choices in CS and related fields. Arguably, the CI framework will help assess/develop CI formations. While numerous researchers have delved into CI contents, processes, and relationships using diverse methodologies and theoretical frameworks, there remains a gap in the literature (Bell-Watkins et al., 2009; Smith et al., 2005; Galliher et al., 2017). Specifically, there is a deficiency in cohesive knowledge regarding universal CI constructs, and there is a need for literature (review studies) that consolidates existing insights while proposing new additions. Such an approach is essential to create a clearer and more comprehensive understanding of the contributing constructs in the establishment of frameworks for developing students' CI. Therefore, this section offers a detailed analysis and discussion of articles, addressing the proposed RQs.

RQ 1: what factors have been linked to CI development?

To fully grasp the factors influencing the CI framework, it is essential to initially evaluate the influential determinants of CI. Through thorough examination, four established constructs, albeit with varying terminologies, have been identified as pivotal determinants of students' CI. These constructs encompass competence/performance, interest, sense of belonging, and recognition within the computing/programming fields, and have been elaborated upon subsequently (Table 1). The findings indicate that perceived competencies/performance in CS are the most examined constructs of CI with 28 articles (≈ 90%) addressing this topic. In contrast, perceived recognition in CS is the least explored, with only 9 articles (≈ 29%). Interest in CS and a sense of belonging in CS are covered in a similar number of articles, 23 (≈ 74%) and 22 (≈ 71%) respectively (Table 1).

Competence/performance in CS

Competence/performance in CS has been identified as one of the constructs influencing CI formation ($n = 28$). When individuals develop proficiency in CS (skills and knowledge), they often begin to identify themselves more strongly associated with the field of computing. Various research studies have used different subscales of related terminologies to define this construct. For instance, terms such as competence in CS (Mahadeo et al., 2020; Taheri, 2019; Taheri et al., 2018; Lunn et al., 2021a,b; Mooney et al., 2018; Parker, 2018), self-efficiency in CS (Deechuay et al., 2016; Hughes et al., 2021; Wofford et al., 2022; Zahedi et al., 2021), performance in CS (Taheri, 2019; Taheri et al., 2018; Hughes et al., 2021; Rollins et al., 2021), confidence in CS (Çakır et al., 2017; Washington et al., 2016; Wofford et al., 2022), ability and knowledge in CS (Kapoor and Gardner-McCune, 2019a; Kapoor and Gardner-Mccune, 2022; Peters and Pears, 2013), experience with computers (Rawhiya Jacob et al., 2022), programming actualization & goal setting (Atman Uslu, 2023; Kong and Lai, 2022; Kong and Wang, 2020), and excellence & leadership in CS (Boyer et al., 2010; Bell-Watkins et al., 2009) have been utilized. A relatively new term of "programming actualization" refers to students employing programming for more elevated and meaningful objectives, thereby facilitating their self-actualization processes (Atman Uslu, 2023; Kong and Lai, 2022; Kong and Wang, 2020). Researchers claim that enhanced computer usage is often linked to better confidence in CS (Tupou and Loveridge, 2019). Additionally, improved confidence and competence with computers lead to a positive attitude in CS, thereby shaping their CI formation (Washington et al., 2016).

Interest in CS

Interest in CS has been recognized as another construct influencing CI formation ($n = 23$), often relating to individuals' willingness to engage deeply within the realm of computer-related tasks and challenges. Authors have defined interest in CS in terms of their self-interest in CS (Mahadeo et al., 2020; Kinnunen et al., 2018; Taheri, 2019; Taheri et al., 2018; Washington et al., 2016; Lunn et al., 2021a,b; Rollins et al., 2021; Kapoor and Gardner-Mccune, 2022; Garcia et al., 2018; Kapoor and Gardner-McCune, 2019b), self-determination in CS (Wofford et al., 2022), engagement in CS (Çakır et al., 2017; Bell-Watkins et al., 2009; Parker, 2018; Peters and Pears, 2013; Kong and Lai, 2022; Kong and Wang, 2020), enjoyment in CS (Zahedi et al., 2021; Kapoor and Gardner-Mccune, 2022; Kapoor and Gardner-McCune, 2019b), satisfaction in CS (Kapoor and Gardner-Mccune, 2022; Kapoor and Gardner-McCune, 2019b), motivation to explore and learn in CS (Wofford et al., 2022; Zahedi et al., 2021), participation and imagination in CS related tasks (Tupou and Loveridge, 2019), and initial positive expectation of university and computing careers (Kinnunen et al., 2018). Kapoor and Gardner identified several factors contributing to students' dedication and interest in pursuing a career in computing. These include their intrinsic interest that stems from engagement in informal activities like hackathons, and participation in professional development opportunities such as internships and conferences (Kapoor and Gardner-Mccune, 2022; Kapoor and Gardner-McCune, 2019b). Frequent computer gameplay was reported to be strongly associated with an increased probability of CS career interest (Shah et al., 2023). According to Peters and Pears (2013), the trajectories of practices that lead to engagement in CS often instigate computer usage. Furthermore, the shift from computer usage to computer programming leads to further engagement in CS (Peters and Pears, 2013). Thus, researchers have concluded that students' engagement in CS will likely impact their perception of being a part of the computing community and eventually impact their CI formation (Peters and Pears, 2013; Tupou and Loveridge, 2019).

Sense of belonging in CS

Another construct, i.e., a sense of belonging, often described as the feeling of "fitting in," plays a critical role in nurturing student interest and persistence ($n = 22$). This concept extends beyond mere inclusion to encompass how individuals perceive their alignment with future career roles in CS and their broader societal roles. To study

TABLE 1 **Study descriptive based on CI constructs that have been employed or investigated.**

Study	Constructs influencing CI				
	Competencies/performance	Interest	Sense of belonging	Recognition	Social context
Washington et al. (2016)	Confidence in CS	Interest in CS	Perception of CS professionals		Ethnic identity
Atman Uslu (2023)	Programming actualization	Programming engagement	Programming imagination and affiliation		Gender disparity
Bell-Watkins et al. (2009)	Excellence and leadership in CS	Engagement in CS	Sense of belonging		Community Outreach, Civic engagement and service
Boyer et al. (2010)	Excellence and leadership in CS				
Çakır et al. (2017)	Confidence and competence	Engagement in CS	Sense of belonging		
Cummings et al. (2019)	Programming resilience, self-efficiency		Sense of belonging		Personal and social identities, support from parents and teachers
Deechuay et al. (2016)	Computing self-efficiency				Parental support
DuBow et al. (2017)	Persistence		Sense of belonging		Support from parents and teachers
Garcia et al. (2018)	Competence in CS	Interest in CS		Recognition by self, family, friends, teachers in CS	
Jacob et al. (2022)	Experience with computers		Perception of CS and computer scientists		Support from parents, friends and teachers, informal learning environments
Kapoor and Gardner-McCune (2019a)	Ability and knowledge in CS	Interest, enjoyment, and satisfaction			informal activities, internships, social support
Kapoor and Gardner-Mccune (2022)	Ability, knowledge in CS,	Self-interest, enjoyment, satisfaction			Informal activities, conferences, clubs
Kinnunen et al. (2018)		Interest, initial expectations of university study and career	Preferred identity of future CS professionals		
Kong and Lai (2022)	Programming empowerment, Programming actualization	Engagement in CS	Programming imagination and affiliation		
Kong and Wang (2020)	Programming actualization, goal setting	Engagement in CS	Programming imagination and affiliation		
Lunn et al. (2021a)	Competence in CS	Interest in CS	Sense of belonging	Recognition by family, friends, and teachers in CS	Educational experiences
Lunn et al. (2021b)	Competence in CS	Interest in CS	Sense of belonging, professional experiences	Recognition by family, friends, and teachers in CS	Cultural experiences
Mahadeo et al. (2020)	Competence in CS	Interest in CS	Sense of belonging	Recognition by family, friends, and teachers in CS	
Mooney et al. (2018)	Competence in CS		Sense of belonging		

(Continued)

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TABLE 1 (Continued)

Study	Constructs influencing CI				
	Competencies/performance	Interest	Sense of belonging	Recognition	Social context
Parker (2018)	Competence in CS	Engagement with Professional Practices	Self-concept of future professional		Internships, capstone courses
Peters and Pears (2013)	Knowledge in CS	Engagement			Experiences of technology in society
Rawhiya Jacob et al. (2022)	Experience with computers	Interest in CS	Perception of CS and Self-perception of computer, scientists		Support from parents, friends, and teachers
Rollins et al. (2021)	Competence and performance in CS	Interest in CS	Interpersonal closeness and STEM centrality	Recognition by family, friends, and teachers in CS	
Shah et al. (2023)	Competence in computer usage				Family's support and interest in CS
Taheri (2019)	Competence and performance in CS	Interest in CS	Sense of belonging	Recognition by self, family, friends, teachers in CS	
Taheri et al. (2018)	Competence and performance in CS	Interest in CS	Sense of belonging	Recognition by self, family, friends, teachers in CS	
Tupou and Loveridge (2019)	Programming, reification, and alignment in CS	Participation and imagination in CS	Perception of CS and future roles in CS		
Wofford et al. (2022)	Self-efficiency and confidence	Self-determination and motivation	Psychosocial perceptions of current and future selves, communal career motivation	Recognition of self and by others	Institutional environments and support in computing departments
Wong (2016)			Perception of CS professional		
Zahedi et al. (2021)	Self-efficiency in CS	Enjoyment, motivation			
Hughes et al. (2021)	Self-efficiency and performance in CS			Recognition by teachers and peers	
Total	28	23	22	9	16

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students' sense of belonging in CS, authors have gaged their perception of CS professionals (Washington et al., 2016; Jacob et al., 2022; Wong, 2016), self-concept of future professionals (Kinnunen et al., 2018; Parker, 2018; Wofford et al., 2022; Tupou and Loveridge, 2019), perception of CS (Rawhiya Jacob et al., 2022; Tupou and Loveridge, 2019; Jacob et al., 2022), programming imagination & affiliation (Atman Uslu, 2023; Kong and Lai, 2022; Kong and Wang, 2020), and communal career motivation (Wofford et al., 2022). In this context, "imagination" involves envisioning potential aspirations and commitments related to computing, while "affiliation" signifies a sense of belonging among peers within the field (Atman Uslu, 2023; Kong and Lai, 2022; Kong and Wang, 2020). And, the communal career motivation of students is crucial as it determines whether their future careers enable them to assist others, contribute to humanity, serve as role models in the community, collaborate effectively with others, and more (Wofford et al., 2022). A better sense of belonging is related to a stronger CI, which in turn leads to greater persistence in computing education and future roles in the field (Mooney et al., 2018).

Recognition in CS

Recognition in CS has been identified as another construct, often involving self-acknowledgment, self-value, and recognition by others in the field, that profoundly influences the development of CI ($n = 9$). When individuals are acknowledged for their achievements or expertise in CS, it reinforces their CI within the CS community. The literature included emphasizes that recognition from parents, teachers, and peers is crucial for the development of students' CI (Mahadeo et al., 2020; Taheri, 2019; Taheri et al., 2018; Lunn et al., 2021a,b; Hughes et al., 2021; Wofford et al., 2022; Rollins et al., 2021; Garcia et al., 2018). According to several studies, self-recognition typically involves seeing oneself as a tech-savvy individual or an exemplary student in the field of computing, which contributes to CI formation (Taheri, 2019; Taheri et al., 2018; Wofford et al., 2022; Garcia et al., 2018).

After investigating the factors associated with CI, the study has compiled a table outlining the characteristics of several studies that specifically focused on the relationship between CI and various factors, constructs, and contexts (refer to Table 2). Most of these studies assessed CI, computing persistence, or computing careers by scrutinizing commonly employed CI constructs, such as interest, competence, recognition, and the sense of belonging in the computing field (Hazari et al., 2010; Taheri, 2019; Taheri et al., 2018; Mooney et al., 2018; Hughes et al., 2021; Garcia et al., 2018). Other studies used slightly different constructs to define CI (i.e., "engagement," "imagination," "affiliation," and "actualization") in gaging CI through computational thinking and programming empowerment (Kong and Lai, 2022; Kong and Wang, 2020). In these articles (Kong and Lai, 2022; Kong and Wang, 2020), "engagement" refers to individual students' active involvement in computing and programming activities, and "imagination" denotes a sense of possible aspirations/commitments of oneself to computing. Additionally, the papers delineated "affiliation," referring to a sense of belonging with peers, and "actualization" as entailing learners' self-actualization in the learning of programming. It's noteworthy that most of these quantitative studies have explored the importance of social context (i.e., school-related factors, support from parents, peers, teachers, ethnocultural background, educational experience etc.) in CI formation (Lunn et al., 2021a,b; Parker, 2018; Deechuay et al., 2016; Wofford et al., 2022; Rawhiya Jacob et al., 2022; Kong and Lai, 2022; Kong and Wang, 2020; Tupou and Loveridge, 2019; Kapoor and Gardner-McCune, 2019b).

RQ 2: what are the established constructs influencing/defining the frameworks for developing students' CI?

While the majority of existing literature addresses various facets of CI, there is a scarcity of research specifically concentrating on validated frameworks for developing students' CI ($n = 11$) (Mahadeo et al., 2020; Taheri, 2019; Taheri et al., 2018; Washington et al., 2016; Bell-Watkins et al., 2009; Lunn et al., 2021b; Rawhiya Jacob et al., 2022; Kong and Lai, 2022; Kong and Wang, 2020; Garcia et al., 2018; Jacob et al., 2022). Most shortlisted articles have developed survey frameworks for measuring CI. These survey frameworks were quantitatively assessed for reliability through confirmatory factor analysis (CFA). Of these studies, four incorporated structural equational modeling (SEM), revealing the relationship (direct, indirect links) between CI and constructs/contexts (Taheri, 2019; Taheri et al., 2018; Kong and Lai, 2022; Kong and Wang, 2020).

In this regard, dichotomizing these studies, we revealed that some research developed a survey model theorizing the CI constructs (performance/competence, interest, sense of belonging, and recognition in computing), which are significant predictors of students' CS-based career aspirations (5) and persistence in CS (Taheri, 2019; Taheri et al., 2018). Likewise, Washington et al. (2016) proposed a survey instrument named CSAIS (computer science attitude and identity survey), which investigated students' confidence, interest, gender, and professional identity to measure the impact of identity development on CS students. A study by Garcia et al. (2018) also established a survey instrument examining the CI of high-achieving underserved computing students based on recognition, interest, and competencies in CS. Their study findings were insightful in showcasing those females (than males), students in IT (than CS, CE), and freshmen (than juniors/seniors) have lower levels of CI (Garcia et al., 2018). On the contrary, some studies employed a framework using survey instruments to measure students' identity in CS by examining constructs such as students' experiences with computers and perception of CS (performance/interest), their perceptions as computer scientists (recognition), and their family support (social context) (Rawhiya Jacob et al., 2022; Jacob et al., 2022).

A few studies employed CI frameworks that incorporated structural equation modeling (SEM), thereby revealing the relationship between CI and constructs/contexts/processes (Taheri, 2019; Taheri et al., 2018; Kong and Lai, 2022; Kong and Wang, 2020). SEM is an analytical instrument employed to establish quantitative relationships, explaining direct/indirect links. In this regard, findings from a study by Taheri (2019) and Taheri et al. (2018) are thought-provoking, as they showcase that "interest" in computing has the strongest direct effect on computing persistence. Students' computing "competencies" are also significant predictors of computing persistence with both direct and indirect effects (Taheri, 2019; Taheri et al., 2018). "Recognition" in computing has both direct and indirect effects on persistence (Taheri, 2019; Taheri et al., 2018). "Sense of

TABLE 2 Studies gaging the quantitative relationship of CI with constructs/contexts.

S. No.	Study	Relationships studied
1	Atman Uslu (2023)	CT (computational thinking) performance and CT self-efficiency ↔academic resilience and CI
2	Cummings et al. (2019)	Adaptive, resilient identity ↔ CI
3	Deechuay et al. (2016)	Parental support ↔ CI (computing self-efficiency, value belief)
4	Garcia et al. (2018)	Recognition, interest, competence ↔CI
5	Jacob et al. (2022)	Experience with computers, perception of CS, social supports, perception of computer scientists ↔ CI
6	Kapoor and Gardner-McCune (2019a)	Self-interest, ability, personality, enjoyment, satisfaction, knowledge, utility, perception, informal activities, social support ↔ CI
7	Kong and Lai (2022)	Programming empowerment ↔ CI (Engagement, imagination, affiliation)
8	Kong and Wang (2020)	Computational thinking (ability to express, connect, and question) ↔ CT perspectives (Programming engagement, affiliation, actualization, goal setting)
9	Lunn et al. (2021a)	Educational experiences relating to computing ↔ CI
10	Lunn et al. (2021b)	Professional experience, cultural experience ↔ CI
11	Mooney et al. (2018)	Sense of belonging in computing↔ CI
12	Parker (2018)	Computing professional identity ↔ CI
13	Rollins et al. (2021)	Interpersonal closeness, competence in CS, performance, recognition, STEM centrality ↔ CI
14	Taheri (2019)	CI constructs (competence, performance, recognition, sense of belonging) ↔ computing academic persistence
15	Taheri et al. (2018)	CI constructs (competence, performance, recognition, sense of belonging) ↔ computing academic persistence
16	Tupou and Loveridge (2019)	Participation, imagination, reification, and alignment in CS ↔ CI
17	Wofford et al. (2022)	Academic psychosocial perceptions ↔ CI
18	Hughes et al. (2021)	Recognition in computing↔ CI

↔shows direct/indirect quantitative relationship between the CI, factors, constructs, or context.

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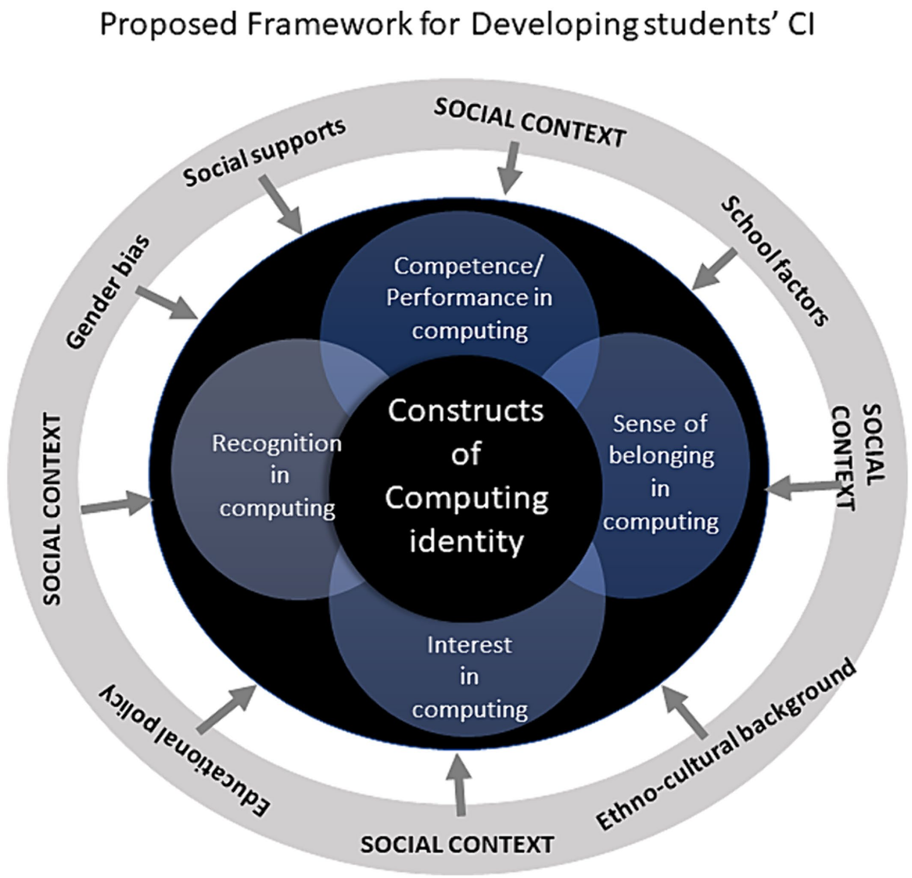

FIGURE 3
The proposed framework for developing students' CI, depicting the influential factors.

belonging" in computing has a direct effect on CS competence and thereby influences persistence (Taheri, 2019; Taheri et al., 2018). Another study carried out by Kong and Lai (2022) based on SEM analysis depicted the relationship between programming empowerment and CI. These researchers investigated the links between infrequent sub-constructs for programming empowerment (i.e., meaningfulness, self-efficiency, and impact) and CI (engagement, imagination, and affiliation). Their findings illustrate that perceived "meaningfulness" and "self-efficiency" in programming are positively related to all sub-constructs of CI (i.e., engagement, imagination, and affiliation). However, the perceived "impact" of programming was only related to students' future imagination about computing/careers, not to current engagement and affiliation in computing (Kong and Lai, 2022). Other research undertaken by Kong and Wang (2020) revealed a significant relationship between CT perspectives (ability to express, connect, and question) and CI constructs (engagement, affiliation, actualization, goal setting). Findings from this study reveal that students' "ability to question" can foster CI formation through their "ability to express" while their "ability to connect" can directly foster CI formation (Kong and Wang, 2020). Additionally, study by Bell-Watkins et al. (2009), emphasizes a framework for K^{-12} computing standards. In their study, the constructs considered in developing the CI were "technical excellence" in CS, "leadership," "civic engagement and service," and "community outreach." The framework was based on the principles including (1) identity development, (2) psychological support, (3) social support, (4) academic support, (5) sense of belonging, and (6) leadership development. According to them, the establishment of framework to develop CI was a significant tool for navigating computing-related curricular standards and for identifying CS-related course characteristics that would maximize the impact of nurturing computing identities in K-12 students (Bell-Watkins et al., 2009). After gaining insights into established constructs and their interrelationships influencing the framework for developing CI, the study aims to explore potential new additions to enhance and expand the existing frameworks defining CI.

RQ 3: what potential additions could further enrich these frameworks to align with the requisites of today's tech-savvy world?

It is noteworthy that a significant portion of the studies has explored the importance of the "social context" ($n = 16$; $\approx 52\%$). The literature extensively examines how the social environment influences students' CI, encompassing factors such as gender bias, community outreach, civic engagement, school-related aspects, informal learning environments, educational experiences, support from parents, peers, and teachers, as well as considerations related to socio/ethnocultural backgrounds, among others. Figure 3 visually depicts these elements, providing a graphical representation that enhances understanding of the framework for developing students' CI, based on its constructs. This illustration serves as a valuable tool for researchers seeking to develop or validate instruments for assessing and fostering students' CI. Therefore, a potential addition to the existing CI frameworks is the inclusion of the "social context." Interestingly, while the social context is not typically defined as a direct construct of CI, many studies have included and evaluated this concept due to its profound influence on CI formation (see Table 1).

When gaging the individual studies critically, studies conducted by Çakır et al. (2017) and Zahedi et al. (2021), underscore the importance of the social environment within school settings, particularly through game-based workshops, as a means to enhance students' interest in computing through identity exploration. Consequently, there is a recognized need for a curriculum focused on programming, as asserted by Kong and Lai (2022), Kong and Wang (2020) and reiterated by Jacob et al. (2022). Their research indicates that participation in a culturally and linguistically responsive computer science curriculum over the course of a year is pivotal for the development of CI. According to Kong and Lai, research/job experiences, mentoring others, club participation, presenting, networking, and obtaining. Help from advisors, working with others, and having encouraging friends in computing have a positive effect on developing CI (Kong and Lai, 2022). Wofford et al. (2022) further reveal that sustaining the aspirations of undergraduate students in computing relies on positive social environments and interactions, which significantly contribute to the development of CI. Additionally, educational experiences, such as internships, supportive teachers, engagement in coursework, and peer mentoring, are crucial for CI development (Bell-Watkins et al., 2009; Lunn et al., 2021a; Parker, 2018; Kapoor and Gardner-McCune, 2019a; Jacob et al., 2022). According to Kapoor and Gardner, the formation of CI involves intrinsic interest and confidence in their abilities, the relevance of coursework, engagement in informal activities like hackathons, and participation in professional development opportunities such as internships and conferences (Kapoor and Gardner-Mccune, 2022; Kapoor and Gardner-McCune, 2019b). Social support and early exposure to computers are also identified as vital aspects of computing identity development (DuBow et al., 2017). Furthermore, Deechuay et al. (2016) find that social support for using computers, both from parents and peers, positively correlates with computer self-efficacy and value beliefs in both male and female students, ultimately contributing to the development of CI. In addition, a gender-enriched study by DuBow et al. (2017) inspected factors influencing the CI of females. Their qualitative findings revealed that females who are persistent in CS-related fields believe that having an early reinforced CI, and supportive computing communities at home/school are critical in the development of CI.

In summary, the "social context" plays a crucial role in influencing competence, interest, sense of belonging, and recognition in computing, by shaping the multifaceted process of CI formation (Rodriguez and Lehman, 2017; Rodriguez et al., 2020; Rodriguez and Stevens, 2023). CI in this context is not singular but rather a composite of interacting constructs within a social framework. This phenomenon has been extensively comprehended through disciplinary identity theory, in conjunction with SCCT. This combination showcases the influence of personal, environmental, and motivational factors on educational and career choices, thereby impacting CI formation. For instance, social interactions within educational settings and professional communities, mentorship programs, and peer interactions can provide opportunities for skills and knowledge development and contribute to building "competence/performance" in CS (Çakır et al., 2017; Boyer et al., 2010; Hughes et al., 2021; Zahedi et al., 2021; Rollins et al., 2021). Social influences, such as role models in the CS community, or supportive peer networks, can spark and sustain students' "interest" in computing. Exposure to diverse perspectives and experiences (personal, educational, professional) through social interactions broadens students' understanding and appreciation of CS domains. Social contexts, including supportive peer groups, perception of future roles, professional value beliefs, and recognition of diverse contributions, foster a "sense of belonging" in CS. Students who feel accepted and valued, i.e., "recognized" within their CS communities are more likely to identify themselves as part of the field and engage actively in learning and career pursuits. According to Morelock (2017), experiences, and environmental and social conditions work in conjugation for positive identity formation. In essence, the social context provides a foundation and reinforcement for the development of competence, interest, sense of belonging, and recognition in CS. By nurturing supportive social environments and promoting inclusive practices, educators and institutions can enhance students' computing identities and facilitate their success in the field (Chen et al., 2023). Consequently, it is proposed as a potential new addition to the CI framework. This inclusion is anticipated to contribute to a more nuanced and comprehensive conceptualization of CI frameworks, fostering a better understanding of the multifaceted factors shaping CI.

Conclusion

This systematic review provides a synthesized and comprehensive framework for developing the CI, consolidating various constructs and factors pivotal to its development. The review extensively examines the factors influencing the formation of students' CI. The findings identify related terminologies and subscales of the established constructs such as competencies/performance, interest, recognition, and sense of belonging within the realm of computing. For instance, some studies have employed terms like actualization, goal setting, affiliation, and engagement in CS to describe CI constructs, which collectively emphasize the same aforementioned CI constructs. A significant observation from the review is the varying depth of research across these constructs. Competencies/performance in CS has emerged as the most extensively studied aspect of CI, whereas perceived recognition in CS remained comparatively underexplored in the literature. This imbalance underscores opportunities for further investigation into how recognition influences CI development and its implications for educational strategies and policies.

In summary, the synthesis of the literature reveals that the existing framework for developing students' CI is predominantly characterized by four core constructs: recognition, performance, interest, and a sense of belonging in computing contexts. These constructs operate within and are influenced by the broader social contexts in which students engage with computing education and practice. Thus, CI is a multifaceted domain that includes the four core constructs, all of which are intricately intertwined with the social context in which they manifest. Conclusively, this paper proposes a refined CI framework based on a comprehensive analysis of existing literature and identified gaps, by including "social context." By deepening our understanding of the multifaceted factors shaping CI, this framework aims to provide educators, policymakers, and researchers with valuable insights into fostering positive identity formation in computing. It is anticipated that this study will guide efforts toward enhancing educational practices that support the development of robust CI among students, ultimately contributing to the advancement of the field.

The findings of this study should be considered in light of certain limitations. Such as the concept of identity is inherently vague, and previous systematic reviews have utilized various search terms like "self-concept," "self-perception," "self-image," "reflective practice," and "professional values," among others. In this study, we focused primarily on specific search terms related to computing identity, such as "CI," "identity in CS," "programming identity," and "coding identity," during the article search process. This approach aimed to ensure the relevance of the article as per the scope of the review. While the study synthesizes findings across multiple articles, the generalizability of conclusions may vary depending on specific contexts, such as educational systems, cultural backgrounds, and demographic characteristics of student populations. Future comparative studies across different educational settings or cultural contexts could provide richer insights into these dynamics. Given the significant role of social contexts in shaping CI, future studies could explore its direct influence on CI formation. The proposed refined framework for developing CI could be validated through quantitative empirical studies across diverse student populations and educational settings.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

MS: Data curation, Formal analysis, Writing – original draft. NS: Methodology, Writing – original draft. AS: Validation, Writing – review & editing. JB: Validation, Writing – review & editing. ZA: Conceptualization, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1366906/full#supplementary-material

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