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Professional identity development in bioscience education: A systematic review of the literature

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This article addressed the significant issue of identity crisis experienced by students in their choice of profession, as highlighted in various research studies. The importance of examining professional was emphasized to identity development from a disciplinary perspective, particularly in the biosciences and allied fields. To achieve this, we conducted a synthesis of 85 research articles, aiming to comprehend the definitions and measurement approaches employed in understanding professional identity and its development within these disciplines. Our analysis also encompasses a summary of the factors influencing professional identity development, coupled with strategies to support it. The findings suggest that professional identity is linked to an individual's persistence and success in a given profession. This research provides valuable insights for researchers and educators striving to create an optimal learning environment that facilitates students in exploring and shaping their professional identities.

Key words: Professional identity, professional identity development, bioscience education, systematic review.

INTRODUCTION

Identity encompasses our self-understanding, shaping how we perceive ourselves and convey this to others, integrating personal and interpersonal dimensions, including cultural and social relationships (Holland, 2001). Individuals navigate multiple identities throughout their lives, undergoing significant transformations (Ibarra, 2007). The development of identity is crucial, as it contributes to students' success in their chosen occupations (Kuchynka et al., 2019; Le et al., 2019; Estrada et al., 2018).

Professional identity (PI) specifically refers to our perception of self within the occupational context and how we communicate this to others (Neary, 2014). Professional identity development (PID) is a transformative process guiding novices toward becoming seasoned professionals. Students' sense of professional identity significantly influences their engagement in learning, facilitating the acquisition of domain knowledge, skills, values, attitudes, and attributes (Dyer and Taylor, 2012; Robinson and McDonald, 2014; Nadelson et al., 2015; Yazdani et al., 2016; Hanauer et al., 2016).

Establishing a robust professional identity is instrumental for students to adapt successfully to the learning environment, engage in professional and creative

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pursuits, and navigate social and cultural changes (Gertsog et al., 2017; Joynes, 2017). While professional identity development can help counteract negative social stereotypes (Kim-Prieto et al., 2013), challenges arise when students struggle to construct a meaningful professional identity (Armitage-Chan, 2016). Notably, traditional science courses emphasizing rote-learning can hinder students in forming a meaningful science identity, impacting dropout rates (Le et al., 2019; Carlone et al., 2014).

Research underscores the enduring impact of professional identity development during undergraduate years, extending beyond academic pursuits (Price et al., 2018). Positive correlations exist between professional identity and students' persistence in their chosen career pathways (Estrada et al., 2011; Clark et al., 2011; Kuchynka et al., 2019; Frantz et al., 2017; Estrada et al., 2018; Vincent-Ruz and Schunn, 2018; Le et al., 2019; Shuster et al., 2019).

Formal definitions of professional identity and its development are evident across various disciplines, including psychology and sociology (Fearon, 1999; Howard, 2000; Mrdjenovich and Moore, 2004; Hirschy et al., 2015), teacher education (Beijaard et al., 2013; Rodrigues and Mogarro, 2019; Hanna et al., 2019), sports (Cardoso et al., 2014), and various STEM fields (Trede et al., 2012). In sociology, identity is described as a social category defined by membership norms, characteristic attributes, and anticipated behaviors (Fearon, 1999). In psychology, professional identity is defined as the sense of connection to the field's values, ideals, and foci (f and Moore, 2004). In the realm of teacher identities, professionals are defined by their practices or activities (what they do) as well as their roles or states (who they are) (Cheung, 2008).

Within bioscience education, researchers have demonstrated that undergraduate students' identities not only influence classroom experiences but also impact their willingness to persist in the discipline (Le et al., 2019). The Vision and Change in Undergraduate Biology Education: A Call to action report in 2011 emphasized the importance of undergraduates comprehending not only the scientific process but also the interdisciplinary nature of modern biology and its integration with society. The evolution of knowledge in biological sciences, the disparity between how biology is taught and practiced, and an enhanced understanding of how people learn underscore the necessity for reform in undergraduate biology education (Vision and Change, 2018). Despite ongoing reform efforts in undergraduate bioscience education, one critical aspect often overlooked is attention to the development of students' professional identity.

The development of professional identity occurs within the framework of a discipline and is shaped by the discipline's "rules of membership" (Brownell and Tanner, 2012). Therefore, it is crucial to comprehend professional identity (PI) and its development (PID) within the specific context of a discipline. In the field of biosciences, the impact of theoretical research on human lives is evident, where a small alteration in a genetic code can lead to a cascade of either desirable or undesirable life events. Biologists, through *in-vitro* observations, can elucidate and provide insights into phenomena occurring in-vivo. For instance, understanding the relationship between drugs dissolved in-vitro and its absorption in-vivo is foundational to drug manufacturing and usage (Dunne et al., 1999). This form of learning, termed instrumental learning, involves acquiring domain knowledge and disciplinary practices essential for professional engagement.

In a similar vein, the transfer of skills from an expert doctor to a junior doctor carries both responsibility and accountability, given its direct impact on patient well-being. This professional commitment necessitates a blend of liberal and instrumental learning, ensuring that patient care remains uncompromised. When examining professional identity development (PID) in the context of biosciences, and offering guidance to educators aiming to foster PID in their students, it becomes imperative to delve into the research defining and measuring PI. Additionally, understanding the strategies and programs implemented for PID in the biosciences domain is crucial. This article conducts a systematic review, analyzing literature on professional identity and its development in bioscience and allied fields. The focus is on comprehending the construct of professional identity, the developmental process, associated factors and challenges, as well as interventions for fostering PI in biosciences disciplines. The objective of our review is to gain insight into:

1) RQ 1 - How is professional identity being defined theoretically and operationally?
2) RQ 2 - How is professional identity measured?
3) RQ 3 -What factors affecting professional identity development?
4) RQ 4 - What strategies and interventions support the development of PI?

METHODOLOGY

The authors adopted the conceptualization of professional identity (PI) to encompass higher education research, programs, and learning experiences in the biosciences and allied domains, all designed with the overarching goal of facilitating the development of PI. Throughout this review, primary objective was to underscore a comprehensive understanding of the concept of PI, the developmental process it entails, the methods and tools utilized for measuring PI, and the strategies implemented to facilitate its development. To achieve this goal, we employed a systematic review process to scrutinize the existing literature on professional identity.

The systematic review and selection process

For the systematic review, we adhered to the internationally recognized PRISMA guidelines, which outline criteria for conducting and reporting systematic reviews and meta-analyses (Page et al.,

Table 1. Keywords used for searching research articles.

Set 1		Set 2
Professional identity search terms	Operator	Bioscience education search terms
Identity OR science identity OR professional identity OR professionalism OR professional identity development OR professional identity formation	AND	Biology OR bioscience OR undergraduates OR higher education

Table 2. Inclusion/exclusion criteria for paper selection.

Inclusion criteria	Exclusion criteria
Research articles, review articles, letters or short reports	Book reviews, Commentaries, Conference materials, data notes, data sets, posters/slides and thesis dissertations
Domain: Bioscience, medicine, health science, other allied professions	Other out of scope domains: Sociology, psychology, management, technology, engineering, mathematics etc.
Level: Undergraduate and professional	Level: Elementary and high school

2021). Two sets of search terms, as outlined in Table 1 were employed across various databases, including SCOPUS, search engines like Google Scholar and Semantic Scholar, PubMed Central, and bioscience journals such as JBSE, CBE-LSE, BMC, PLOS Biology. The first set of terms aimed to narrow down the focus on studies related to professional identity, while the second set was designed to identify studies within the realm of bioscience education. The operator "OR" was used to separate search terms within each set, and the "AND" operator was utilized to combine search terms from the two sets.

This review considered studies published between January 2000 and December 2020. While the primary focus was on this time frame, a few research studies predating 2000 were included, given the limited availability of studies on professional identity development in the bioscience and allied domains during that period. The process flow for the identification and screening of research articles included in this literature review is depicted in Figure 1.

Screening and eligibility criteria

The research studies were screened for eligibility using a set of inclusion and exclusion criteria (Table 2).

Data coding and analysis

Our coding scheme encompassed the following categories: (a) publication information (author, year, and type of publication); (b) domain and subdomain of study; (c) general study information (key constructs/concepts and their definitions, gap and motivation behind the study, research questions driving the study, study duration, sample size, data collected, tools used for data collection); (d) methodology (qualitative, quantitative, mixed); (e) data analysis procedure; (f) key findings.

Out of the 85 articles considered for full-text review (Figure 1), 58 articles were coded based on their relevance to the research questions in focus. Fragments related to Research Question 1 (RQ1) were coded according to the theoretical and operational definitions of professional identity, while fragments for Research Question 2 (RQ2) pertained to the measurement of PID. Fragments addressing Research Question 3 (RQ3) were coded to cover factors affecting the development of PI, and fragments related to Research Question 4 (RQ4) were concerned with strategies and interventions supporting the development of PI. A fragment is defined as a single word or a set of words in a sentence or sometimes multiple sentences that represent the same construct or convey similar meaning. Throughout the study, 86 fragments were coded for RQ1, 39 fragments for RQ2, 178 fragments for RQ3, and 71 fragments for RQ4. Similar codes were subsequently merged after examining the results from the open coding process. The coded fragments were then summarized to guide the description of findings.

FINDINGS

To enhance our comprehension of professional identity (PI), part 3.1 initiates by examining how PI is defined in various contexts. Following this, part 3.2 delves into different measurement tools and instruments, exploring how they have been utilized to measure various aspects of PI and its development. Part 3.3 addresses the diverse factors and situations encountered by learners that impact their PI development. The discussion within this section aims to elucidate the understanding of these factors and their influence on PI development, paving the way for various academic interventions designed to support this development. Taking into account one or multiple factors, part 3.4 provides an overview of programs specifically crafted for the development of PI.

Understanding of professional identity

The understanding of professional identity as a construct involves research studies that focus on defining, understanding, explaining, and exploring the construct of PI from a theoretical perspective. Given the complexity of the concept of identity, research has delved into the nature and role of identity to enhance comprehension. In the case of professional identity, a singular definition is elusive, leading to varied contextual definitions in the literature.

These contextual definitions encompass qualities of an

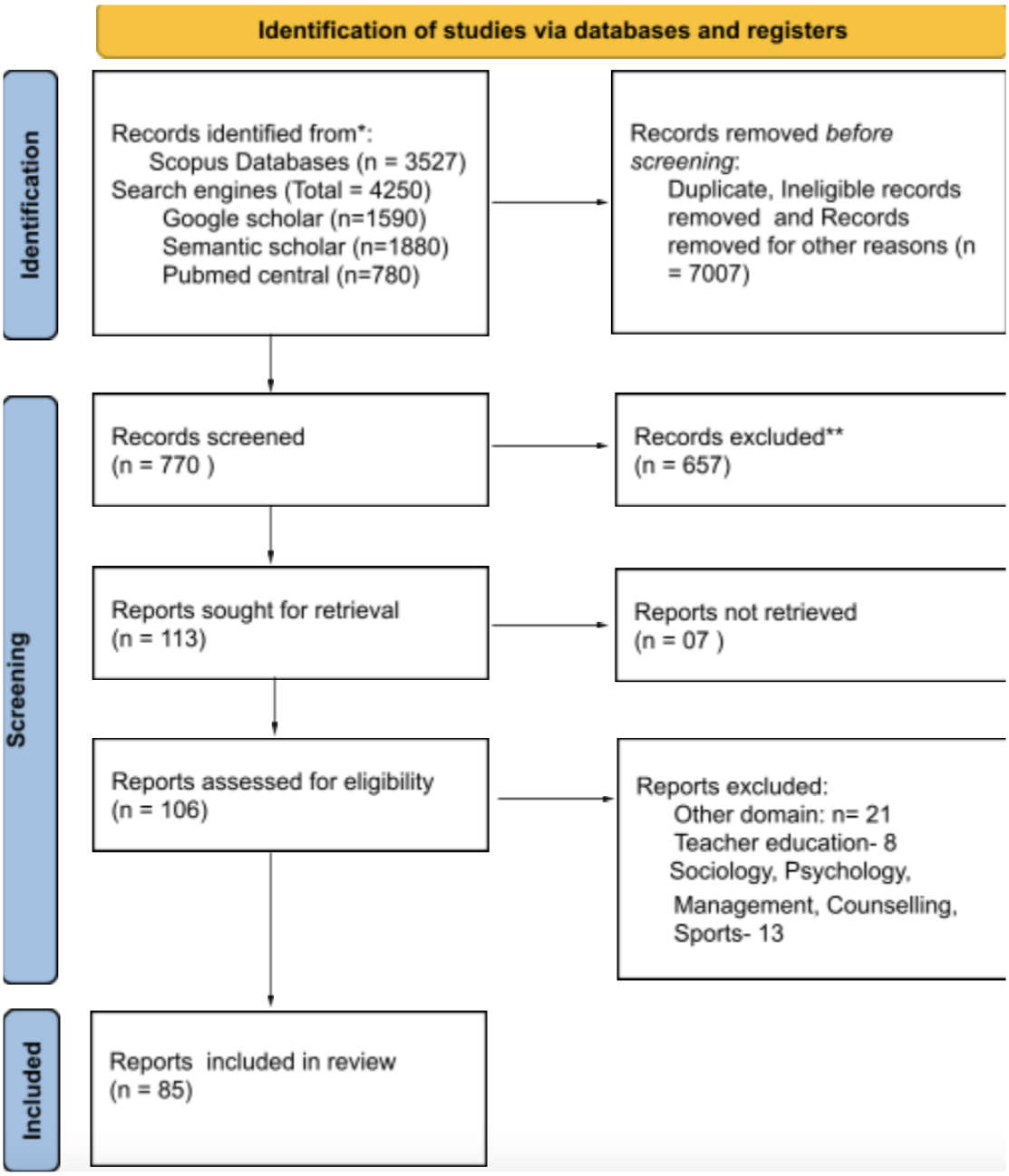

Figure 1. PRISMA flow diagram.

individual, such as dedication towards assigned work (Shahabi et al., 2020), self-views and perceptions (Vincent-Ruz and Schunn, 2018; O'Leary and Cantillon, 2020), and attributes, skills, knowledge, beliefs, practices, and principles representative of professionals within a given profession (Nadelson et al., 2015). Table 3 provides descriptions of codes utilized for defining professional identity, incorporating elements such as self-awareness, understanding one's capabilities, recognizing roles and responsibilities associated with a profession, and acquiring relevant knowledge applicable in different contexts.

Tools and instruments for measuring PI

Various tools and instruments, such as questionnaires, self-reporting surveys, tests, and measurement scales, have been developed, adapted, and modified to measure professional identity in different contexts. These instruments are specifically designed for assessing professional identity and competencies, contributing to the evaluation of the professional identity development (PID) process. Since professional identity cannot be directly measured or quantified, different dimensions, including

Table 3. Codes related to RQ1: Defining professional identity.

S/N	Code name	Description	References
1	Professional conduct	Commitment to a profession, understanding rules and responsibilities and applying it. Familiarity, application and adoption of duties, respecting workplace relationships, abiding by rules and norms of profession.	Mrdjenovich and Moore, 2004; Olckers et al., 2007; Thiry et al., 2012; Goldie, 2012; Goldstein et al., 2014; Nadelson et al., 2015; Shapiro et al., 2015; Yazdani et al., 2016; Wallenburg et al., 2016; Kalet et al., 2016; Mylrea et al., 2017; Joynes, 2017; Wald et al., 2019; Shahabi et al., 2020.
2	Acquisition and application of knowledge in different contexts	Being knowledgeable and drawing on/ reproducing the relevant Scientific/domain/disciplinary knowledge and applying it in a given situation/context	
2a	Domain knowledge	Domain specific knowledge of Integrated health professionals' intra and inter-personal domain knowledge Biomedical and behavioral sciences STEM Medical profession Interdisciplinary program- neuroscience, brain Mapping and Connectomics (BM&C), biomedical sciences, biosciences, Interprofessional education- medical and nursing, pharmaceuticals.	Olckers et al., 2007; Chang et al., 2011; Thiry et al., 2012; Goldie, 2012; Robinson and McDonald, 2014; Goldstein et al., 2014; Ullrich et al., 2014; Peeters and Vaidya, 2016; Yazdani et al., 2016; Hancock and Walsh, 2016; Remich et al., 2016; Frantz et al., 2017; Visser et al., 2017; D'Arcy et al., 2019.
2b	Disciplinary practices	Having a sound grasp of the facts and scientific evidence, sense-making, critical thinking. Understanding the scientific research process, fidelity to patients, clinical skills, compassion, integrity, information gathering, and creative thinking, practice of the scientific approach, doing experiments, and using equipment. Engaging in scientific research such as hands on experience with laboratory technical skills, scientific communication (SC) skills.	Olckers et al., 2007; Thiry et al., 2012; Robinson and McDonald, 2014; Shapiro et al., 2015; Yazdani et al., 2016; Matias et al., 2019; Cameron et al., 2020.
2c	General skills	Oral and written communication, creativity, innovativeness, literacy, time management, independence and teamwork, public speaking.	Robinson and McDonald, 2014; Allen-Ramdial and Campbell, 2014; Ullrich et al., 2014; Kedraka, 2015; Matias et al., 2019.
3	Self-consciousness (awareness, perception and reflections)	What comes to mind when one thinks about oneself and what one believes to be true about one self? It includes views about self, identification and representation of self as a part of the profession and changes occurring in these views/representations. It implies being aware of one's own capabilities and acting on it as appropriate; exhibiting expert knowledge when needed. Reflecting on your experiences, practices, assumptions, actions and reactions, behaviors, decisions and choices made.	Olckers et al., 2007; Clark et al., 2011; Brownell and Tanner, 2012; Kim-Prieto et al., 2013; Trujillo and Tanner, 2014; Goldstein et al., 2014; Kedraka, 2015; Shapiro et al., 2015; Peeters and Vaidya, 2016; Wallenburg et al., 2016; Frantz et al., 2017; Monrouxe et al., 2017; Stets et a., 2017; Kalet et al., 2016; Mylrea et al., 2017; Vieira et al., 2017; Vincent-Ruz and Schunn, 2018; Rowland et al., 2019; Wald et al., 2019; Cruess et al., 2019; Matias et al., 2019; Cameron et al., 2020; O'Leary and Cantillon, 2020.

competence in terms of subject-specific and interdisciplinary knowledge, professional skills (both domain-specific and general), and thinking skills like critical thinking, have been targeted for measurement.

The assessment also extends to indicative factors influencing professional identity development, encompassing aspects such as self-efficacy, ownership, community values, interest, motivation, and commitment. Table 4 offers a concise overview of different measurement methods, while Table 5 provides detailed information on various instruments from the literature. While these instruments may be specific to certain domains and contexts, researchers and educators can modify and adapt them to suit their particular circumstances.

Transformative experiences and other factors affecting the development of PI

The development of professional identity is influenced by numerous factors and experiences

Table 4. Codes related to RQ2: Measuring professional identity and it's development.

S/N	No Code name	Description	References
1	Measurement of affective states	Different emotional/affective states experienced such as burnout, anxiety, frustration, anger, despair, stress, confusion, dilemma etc	Edwards and Dirette, 2010; Frantz et al., 2017; Monrouxe et al., 2017
2	Measurement of scientific identity development	Through survey questionnaire, identity scales, essays, instruments etc	Olckers et al., 2007; Edwards and Dirette, 2010; Thiry et al., 2012; Goldie, 2012; Kim-Prieto et al., 2013; Nadelson et al., 2015; Peeters and Vaidya, 2016; Hanauer et al., 2016; Frantz et al., 2017; Monrouxe et al., 2017; Kalet et al., 2016; D'Arcy et al., 2019; McDonald et al., 2019a; Cameron et al., 2020; Esparza et al., 2020
3	Measuring motivation, commitment and persistence	The motivation to persist in a profession and being committed to the professional values and duties.	Trujillo and Tanner, 2014; Hanauer et al., 2016; Guraya, 2016; Frantzet al., 2017; Esparza et al., 2020
4	Measuring self-efficacy	The confidence to carry out a specific task or perform within a specific domain of skills	(Trujillo and Tanner, 2014; Hanauer et al., 2016; Frantz et al., 2017; Cheng and Chen, 2019; Shuster et al. 2019).

Table 5. Instruments used for measuring PID.

Tool/Instrument	Description	Construct(s) being measured	References
Science identity scale (SCID), science identity survey (SIS)	A 5/3* item instrument ona 5/7* point likert scale (Strongly disagree to strongly agree)	Sense of belonging to the community of scientists, Personal satisfaction from working on a team, perception of self, belonging to the field of science, and the work of a scientist is appealing	Cameron et al., 2020; Esparza et al., 2020; D'Arcy et al., 2019; Shuster et al, 2019; Hernandez et al., 2017, Frantz et al., 2017, Hernandez-Matias et al., 2019.
Role identity survey (RIS)	Self-reporting questionnaires consisting of 26 items across the 4 factors	Competence, interest, self-recognition and recognition by others	Paul et al., 2020.
Quantitative measurement instruments for teacher identity	59 components analyzed across the 6 domains of teacher identity	Self-image, motivation, commitment, self-efficacy, task perception, and job satisfaction	Hanna et al., 2019.
A medical professional competence instrument	A scale consisting of eight factors with 51 items	Essential medical knowledge, public health or social science, essential clinical skills, advanced clinical skills, communication skills, advanced study skills, critical thinking and adaptation, and professionalism.	Cheng and Chen, 2019.
Professional identity essay (PIE)	Responding to essay questions developed based on Kegan's model	Stages of PID The instrumental, socialised, self-authoring and self-transforming mind	Kalet et al., 2016.
Defining Issues Test, Version 2	Responding to moral dilemma situations presented	Personal interest Maintaining norms and Post-conventional thinking	Kalet et al., 2016.
Persistence in the sciences (PITS) survey	A 5-point likert scale questionnaire with 36items	Project ownership, self-efficacy, science identity, community values and networking	Hanauer et al., 2016.
URSSA instruments	A 136-item instrument	Thinking and working like a scientist, personal/professional gains, becoming a scientist/professional	Thiry et al., 2012.

Table 5. Cont'd.

Professional identity questionnaire (PIQ) For undergraduate students (PIQUS)	5 demographic questions and 10 Likert scale questions 23 items on 5-point likert scale	Perceived roles, status, Education, and respect in the profession of occupational therapy. Four dimensions: cognition (five items), emotionality (eight items), behaviour (sixitems) and fitness (four items)	Edwards and Dirette, 2010; Wang et al., 2019.
SACNAS identity as a scientist scale	16-item self-report scale, from 1 (strongly disagree) to 7(strongly agree)	Students' self-perceptions about their identity as a scientist.	Kim-Prieto et al, 2013.
Transferable skills, key skills confidence scale	A five-point Likert scale, 47 items	Self-perception of acquiring Key transferable skills communication, team work, perseverance, task management, application of theory, problem-solving, critical thinking	Bullock et al., 2012; Thomas et al., 2001.
Self-efficacy scale (Biology), motivational strategies and learning questionnaire (MSLQ), scientific research self-efficacy (SRSE), leadership/team work self-efficacy (LTSE)	21 questions ranking confidence in performing biology-related tasks on a scale from 1 (not at all confident) to 5 (totally confident).	1) Methods of Biology (8 questions), 2) Generalisation to Other Biology/Science Courses and Analyzing Data (7 questions), and 3) Application of Biological Concepts and Skills (6 questions).	Ainscough et al., 2016; Trujillo and Tanner, 2014; Frantz et al., 2017.

that accompany the transition from a novice to a professional.

The transformative experiences during this journey, coupled with the associated emotions, impact this transition significantly. Learners undergo continuous evolution, grappling with challenges and barriers that may induce stress, anxiety, burnout, depression, dilemmas, and cognitive disequilibrium (Austin, 2007; Edwards and Dirette, 2010; Kedraka, 2015; Wald et al., 2019). These challenges, in turn, affect learners' efficiency, subsequently impacting their retention and persistence in the domain (Mrdjenovich and Moore, 2004; McCourt et al., 2017; Cooper et al., 2019; Robinson et al., 2018).

Receiving support, motivation, and affirmation at different stages of this transformative process can aid in developing readiness to cope with challenges, fostering resourcefulness and resilience (Visser et al., 2017; Kunhunny and Salmon, 2017). Table 6 delineates the various factors and how they influence the development of professional identity (PID).

Programs, interventions and recommendations to support the development of PI

Various development programs are designed to facilitate the acquisition of domain-specific skills, contributing to the development of confidence and a sense of belonging within a profession. These domain-specific skills encompass clinical skills, practical skills, on-the-job learning including internships, training, workplace preparation, and initiatives to increase workforce capacity. Programs also focus on preparing professionals through hands-on research, authentic experiences, and meaningful practices. Academic and research programs supporting skill development have been implemented through diverse approaches.

Table 7 provides an overview of programs offering research experiences, such as Course-based, short-term, or undergraduate research experience (CURE, URE, STRE), Undergraduate Research Student Self-Assessment (URSSA), Graduate Teaching Assistants Teaching Professional Development (GTA-TPD) (Reeves et al., 2016), Postbaccalaureate Research Education Programs (PREP), collaborative learning models (CLM), apprentice-based programs, Undergraduate Mentoring programs, Co-mentoring, and STEM enrichment programs. These programs have proven effective in fostering the development of students' professional identity.

Highlighting the significance of preparatory programs, a study comparing the acquisition of transferable skills in two groups of students (DIP vs Non-DIP) found that the broad learning gains from these programs cannot be replicated by other elements of the degree program (Bullock et al., 2012).

The literature provides specific guidelines for educators and researchers aiming to support the development of students' professional identity. Recognizing identity formation as a social and relational process, it is emphasized that educators should leverage existing relational settings experienced by their students (Goldie, 2012). Supervision and mentoring play crucial roles in promoting the development of self-authorship by

Table 6. Codes related to RQ3: Factors affecting the development of PI.

S/N	Code name	Description	How a factor affects	References
1	Community of practice (COP)	Learning in and from society and interpersonal relationships. and participation as a member of a particular group/community. Developing a sense of belonging to the group/community.	People's identities play a vital role in putting them in socially compatible places. Students learn to appreciate and coordinate diverse perspectives through meaningful interactions. Interacting with other members of their profession helps to develop PI through Intersection, Dominance, Compartmentalization and merging	Beckett and Gough, 2004; Goldie, 2012; Brownell and Tanner,2012; Kim-Prieto etal, 2013; Allen-Ramdial and Campbell, 2014;Trujillo and Tanner, 2014; Hanauer et al., 2016; Armitage-Chan, 2016; Monrouxe et al., 2017; Kalet et al., 2016; Vieira et al., 2017; Andrews and Aikens, 2018; Vincent-Ruz and Schunn, 2018; Cooper et al., 2019;Cruess et al., 2019; Kuchynka et al., 2019; Shuster et al., 2019; Shahabi et al., 2020; O'Leary and Cantillon, 2020.
2	Support and guidance from peers, mentors and family	Receiving (or not receiving) support, encouragement, motivation, guidance and recognition from family, teachers, mentors that help in transitioning from a novice to an expert.	Professional socialisation- Key socialisation experiences like co-mentoring, guide, mentor, role models, internships, graduate assistantships, student organisations, and early professional positions, community of practice during and after graduate school are associated with the development of professional identity. Mentorship is critical to student retention and persistence in a field. Students feel becoming a professional when they are guided by their mentors to involve in critical thinking and Brainstorming in the domain.	Beckett and Gough, 2004; Edwards and Dirette, 2010; Chang et al., 2011; Kim-Prieto et al., 2013; Illing et al., 2013; Trujillo and Tanner, 2014; Goldstein et al., 2014; Ullrich et al., 2014; Hancock and Walsh, 2016; Kay and Coles, 2018; Andrews and Aikens,2018; Rowland et al., 2019; Hernandez-Matias et al., 2019; Kuchynka et al., 2019; D'Arcy et al., 2019; Cameron et al., 2020; Esparza et al., 2020.
3	Dealing with negative affective states	Experiencing different emotions like frustration, anxiety, stress, burnout, despair, confusions, exhaustion which may cause cognitive disequilibrium or dissonance affecting the development of PI.	Lack of professional standing, identity, and inadequate acknowledgment can lead to burnout, mental exhaustion, depersonalization, and loss of personal achievement. Trainees with strong moral reasoning skills and a commitment to ethical standards are less vulnerable to situational circumstances such as fatigue, uncertainty, and emotional stress leading to a loss of professionalism. Personal and professional identity and goals, Shock situations, stress and coping responses have an impact on the development of professional identity.	Austin, 2007; Edwards and Dirette, 2010; Chang et al., 2011; Trujillo and Tanner, 2014; Kedraka, 2015; Armitage-Chan, 2016; Monrouxe et al., 2017; Kunhunny and Salmon, 2017; Stubbing et al., 2018; Kay and Coles, 2018; Price et al., 2018; Cruess et al., 2019.
4	Self-efficacy	The ability and preparedness to take up roles and responsibilities of a profession, developing competence to achieve personal goals and mastery. This needs both instrumental and These include acquisition of skills and behaviors required for a profession for eg. Leadership qualities, taking ownership, becoming resourceful, navigating through challenges, Knowledge construction, reasoning, sense-making, critical thinking and other domain specific procedural skills.	Competence can affect learners' insufficient conception of their evolving identity, interpretation, and application of knowledge in real-life circumstances. Academic accomplishment, perseverance, and self-regulated learning are all mediated by self-efficacy. Increased self-efficacy in scientific research is considered as a robust benefit for students. A self-directed, engaged individual is a requirement for professional development. A perception of competence requires the individual as a qualified professional.	Beckett and Gough, 2004; Tang and Gan, 2005; Olckers et al., 2007; Edwards and Dirette, 2010; Goldie, 2012; Kim-Prieto et al., 2013; Illing et al., 2013; Robinson and McDonald, 2014; Trujillo and Tanner, 2014; Ullrich et al., 2014; Nadelson et al., 2015; Kedraka, 2015; Hanauer et al., 2016; Frantz et al., 2017; Kunhunny and Salmon, 2017; Kalet et al., 2016; Mylrea et al., 2017; Brace et al.,2018; Kay and Coles, 2018; Cooper et al., 2019; Wald et al., 2019; Hernandez-Matias et al., 2019; Cheng and Chen. 2019; D'Arcy et al., 2019; Shuster et al., 2019; McDonald et al., 2019a; Cameron et al., 2020; Esparza et al., 2020.
5	Learning experiences	Different learning experiences and opportunities that learners come across, which shapes their identity.	Experiences that aid in the structure and management of one's professional development (those that lead to a professional identity) can also aid in self-authorship, critical thinking, and self-evaluation.	Robinson and McDonald, 2014; Kedraka, 2015; Joynes, 2017; Wald et al., 2019; Shahabi et al., 2020.
6	Attitudes and beliefs towards a profession	A person's attitude towards a profession and consequent Behaviors informed by their interest, their prior knowledge and conception about the figured worlds affects the value that they give to a particular task to be performed.	The developmental trajectory of undergraduates' intellectual growth is outlined by differences in their expectations of their cognitive development among novice and experienced students. Students perceive being part of the profession when encouraged to involve in professional domain practices. Identifying oneself as a scientist may lead to better preparedness to succeed in science.	Mrdjenovich and Moore, 2004; Chang et al., 2011; Trujillo and Tanner, 2014; Goldstein et al., 2014; Shapiro et al., 2015; Armitage-Chan, 2016; Guraya, 2016; Drinkwater et al., 2017; Stubbing et al., 2018; Andrews and Aikens, 2018; Price et al., 2018; Vincent-Ruz and Schunn, 2018; Cruess et al., 2019; Rowland et al., 2019; D'Arcy et al., 2019; McDonald et al., 2019a; Shahabi et al., 2020; O'Leary and Cantillon, 2020.

Table 7. Codes related to RQ4: Strategies and interventions to support the development of PI.

S/N	Code name	Description	References
1	Role models and mentors' capacity	Role models and mentors can provide support, guidance, assessment and feedback to learners who are undergoing identity transformation/development	
1a	Support and guidance	Mentors can provide guidance about principles and practices of the profession, Support in building a strong network. Role models can provide encouragement and help learners invalidating their professional identities.	Beckett and Gough, 2004; Clark et al., 2011; Goldie, 2012; Kim-Prieto et al., 2013; Trujillo and Tanner, 2014; Ullrich et al., 2014; Remich et al., 2016; Mylrea et al., 2017; Stubbing et al., 2018; Brace et al., 2018; Cooper et al., 2019; Wald et al., 2019.
1b	Opportunities for reflection	Designing programs and activities that provide the learners with an opportunity to reflect on their actions	Kedraka, 2015; Mylrea et al., 2017; Wald et al., 2019.
1c	Assessment and feedback	Periodic assessment of transferable skills and, receiving feedback from peers and faculty helps improving performance and developing a stronger professional identity.	Fraser et al., 2007; Goldstein,Storey-et al., 2014; Peeters and Vaidya, 2016; Mylrea et al., 2017; Wald et al., 2019.
2	Curriculum integrated programs	Includes authentic, real life research experiences structured to support the development of PI and integrated in the curriculum/academic program.	
2a	Short term research programs, Internships or collaborative projects	Student-Run Biology Workshop (SRBW) Summer research program (BRAIN) A week-long hands-on research and non-research-based summer learning experience A weeklong pre–college engagement STEM Academy (SA) program Carnegie Initiative on the Doctorate (CID) a multi-institutional study Interdisciplinary program Interprofessional education (IPE) and collaborative practice to conceptualize the professional identity of Health and Social Care (H&SC) staff	Ullrich et al., 2014; Kedraka, 2015; Frantz et al., 2017; Joynes, 2017; Hernandez Matias et al., 2019; Kuchynka et al., 2019.
2b	Curriculum integrated, semester-wise/ long-duration research programs	Formal course to senior undergraduate students, Multi-Year Research Experiences Urban semester program (USP) an integrated structured study programme Course-based research experiences (CREs) Postbaccalaureate Research Education Programs (PREP) Curriculum design (pharmacy) based on self-determination theory to provide authentic learning experiences Undergraduate research experiences (UREs) Course-based undergraduate research experience (CURE): Brain Mapping and Connectomics (BM&C) Course-based undergraduate research experience (CURE): Laboratory based course in STEM, extended research projects to be covered in one semester Course-based undergraduate research experience (CURE): An An introductory cell and molecular biology laboratory course	Tang and Gan, 2005; Olckers et al., 2007; Clark et al., 2011; Thiry et al., 2012; Goldstein et al., 2014; Hanauer et al., 2016; Remich et al., 2016; Mylrea et al., 2017; Cooper et al., 2019; D'Arcy et al., 2019; Shuster et al., 2019; Esparza et al., 2020.
2c	Problem-based approaches	The interdisciplinary problem-solving approach, Problem based activities: module that builds on skills acquired by students in their first year, links to other second year modules and culminates in preparation of individual student plans for third year projects or dissertations. ● Research intensive problem-based curricula	Clark et al., 2011; Robinson and McDonald, 2014; Allen-Ramdial and Campbell, 2014.
2d	Authentic and experiential learning	Providing learners with opportunities of authentic and real-life research experiences. Involving them in decision making to give them autonomy and scope to experiment with their identities.	Goldie, 2012; Brownell and Tanner, 2012; Illing et al., 2013; Goldstein et al., 2014; Nadelson et al., 2015; Cruess et al., 2019; Hernandez-Matias et al., 2019; Wagler and Olimpo, 2020; O'Leary and Cantillon, 2020.

encouraging new professionals to reflect on and make sense of expectations, values, relationships, roles, and responsibilities associated with their personal and professional identities (Hirschy et al., 2015; Trujillo and Tanner, 2014; Kim-Prieto et al., 2013).

Reviewing students' online learning experiences allows for the potential design of systems that ensure proper support to meet their learning needs (McCutcheon et al., 2016). Proposed reforms focus on making informed planning for a successful career through the development of a strong professional identity (Hancock and Walsh, 2016). Recommendations underscore the importance of prioritizing support for students' professional identity development through an inquiry process involving discussion and reflection (Rodrigues and Mogarro, 2019). However, the qualitative nature of the development process raises questions regarding the quantification of professional identity.

DISCUSSION

The interaction between an individual and others in the workplace is a crucial factor influencing the evolution of a person's professional identity (PI). These interactions occur at both personal and professional levels, shaping perceptions about the field and the associated responsibilities that define a professional's identity. For novices entering a particular field, the process of learning the specifics and intricacies, while acquiring in-depth domain knowledge, can be overwhelming, leading to burnout, stress, anxiety, and eventual drop-out.

Understanding the real-world applications of theoretical knowledge taught in the curriculum is essential. When learners perceive subject knowledge as relevant and observe its application in the real world, it fosters a sense of personal accomplishment and belonging to the field of study. To address drop-out rates in science and facilitate early development of PI, integrating learners' engagement with authentic real-world research into the curriculum is crucial. This involvement helps them comprehend the skills and practices integral to a profession and acquire them through implementation.

However, designing curriculum-associated research programs alone is insufficient for developing a strong professional identity. It must be complemented by learning from peers, mentors, guides, and colleagues in the workplace to form a community of practice (CoP). This CoP should support learners in acquiring domain knowledge, skills, and practices while maintaining their mental well-being. It aids in familiarizing learners with professional roles and responsibilities, facilitating the internalization of values and norms associated with a profession.

Providing learners with support, encouragement, guidance, and recognition is essential for establishing a sense of belonging to the professional community and aiding in their personal achievements. Having role models and mentors who can offer feedback and involve learners in the decision-making process facilitates autonomy, allowing them to experiment with their professional identities. Conversely, a lack of support in exploring professional identities may lead to missed opportunities, resulting in depersonalization, cognitive dissonance, and emotional exhaustion, hindering the development of professional identity.

Educators should focus on creating a conducive learning environment that offers opportunities for learners to explore their professional identities. When dealing with identities, it's crucial to recognize that it is a continuum, and a one-size-fits-all approach is not suitable. Therefore, learners should be given agency and scaffolding throughout the journey of developing their professional identity.

This long-term process should be regularly monitored with multiple checkpoints to identify learners at risk early on and provide the necessary support for shaping their identities.

Conclusion

This review has addressed the concept of professional identity, defining and operationalizing it in various contexts within the domain of biosciences. The scope of this review paper is limited to bioscience and allied domains, potentially missing insights from other domains or work published in articles beyond the scope of this review. Although reports from reviewed articles on authentic undergraduate research experiences have highlighted various positive outcomes, it remains unclear if these outcomes are consistent across all such programs (Shuster et al., 2019).

The development of professional identity is a dynamic process involving resilience through reflection on actions taken to enhance competence and efficacy while becoming a member of a profession. These actions are influenced by the sense of belonging one has towards a profession and the perception of self in relation to the roles and responsibilities to be undertaken. Understanding the impact of such programs on professional identity development, along with measures and predictors of persistence in the field, would be worth exploring. The development of professional identity is significantly influenced by the surroundings and environment of an individual, which can either support or suppress positive impacts on identity formation.

Future research should focus on understanding the context in which students are situated, as it is crucial for developing and modulating a learning environment employing strategies for fostering professional identity development.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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