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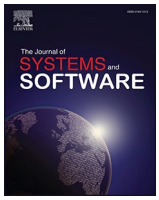

Software engineering competency models and intercultural communication competencies: A systematic literature review

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ABSTRACT

In the field of Software Engineering (SE), educational institutions are confronted with the demanding responsibility of aligning their curricula to provide students with the competencies — soft and technical — demanded by the evolving job market. Moreover, workplaces are becoming increasingly international, highlighting the competencies required in collaborating with people from diverse linguistic and cultural backgrounds. Competency models offer essential input for curriculum design. Moreover, educators may need to construct their own competency models when international guidelines fall short.

To prepare students for future workplaces, curriculum designers necessitate knowledge to address demands of the international working environment. To gain a deeper understanding of the needs in the international SE context, we conducted a systematic literature review (SLR) to identify and analyze existing SE competency models and their construction, as well as investigate communication, collaboration, intercultural, and language competencies embedded in these models.

This SLR identified 29 competency models across diverse application domains and purposes, constructed using a range of mono- and multi-method approaches, and offering multiple use scenarios for diverse stakeholders. We identified and collected an extensive collection of communication, collaboration, intercultural, and language competencies from the competency models in addition to the elements of the competency model construction process.

Regarding identified competencies, communication and collaboration embody as core components in SE competency models whereas intercultural and language competencies are depreciated. Moreover, competency models and their construction lack international aspects. These findings highlight gaps in current competency models and offer insights into curriculum design to better prepare students for international SE environments.

1. Introduction

The field of Software Engineering (SE) is acknowledged for its complexity, collaborative, and international nature. The field requires practitioners to possess a diverse set of soft competencies beyond technical expertise. Educational institutions are, thus, confronted with the demanding responsibility of aligning their curricula to provide students with the topical and relevant competencies demanded by the evolving job market. To respond to these challenges, educators and curriculum designers can utilize existing knowledge of general and more specialized frameworks and curricular guidelines. Such frameworks and guidelines are, for example, the European e-competence framework (ICT-mastery.eu, n.d.), European skills, competences, qualifications, and occupations framework (European Commission, n.d.), curriculum guidelines for undergraduate degree programs in SE (SE2014) (IEEE Computer Society and ACM, 2015), SE competency model (SWECOM) (IEEE Computer Society, 2014), SE body of knowledge (SWEBOK) (IEEE Computer Society, 2024), or computing curricula competency framework (CC2020) (ACM and IEEE Computer Society, 2020). Following common curricular guidelines may not, however, be directly applicable or otherwise suitable to meet the present-day requirements and more specific needs of various companies and positions for local employers and their varying application domains.

In fact, several studies (e.g. Garousi et al., 2020; Radermacher et al., 2014) report on the skills gaps between the software industry and education. Reasons for these skills gaps can be attributed to the curriculum, relating, for example, to industry expansions to new areas, missing feedback from industry, and missing soft skills (Oguz and Oguz, 2019).

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From the perspective of filling the gap, a critical factor can be time (Akdur, 2021); This rapidly changing environment increases pressure on education. The gaps in curricula and labor market mismatch can be filled by own, tailored competency models that can be rather significant – not only to educators but also to students who seek to understand the competencies success requires in their fields. Moreover, competency models help companies identify the critical competencies required to enhance organizational performance and productivity.

Furthermore, the world is ongoing significant changes; immigration is on the rise, and workplaces are becoming increasingly international, even within the field of SE that is already considered international. Many current or future jobs entail a degree of globalization and cultural encounters and call for globally competent software engineers (Clear and Beecham, 2019). The challenges identified in global SE education are increasingly pertinent to the education of both local and immigrant populations; Socio-cultural challenges such as language differences, differing perceptions of time, assumptions about national cultures, variations in autonomy, and work habits (Hoda et al., 2017) are particularly relevant – not only in education but also in the international workplaces where individuals from diverse linguistic and cultural backgrounds collaborate.

A multicultural working environment imposes evidently more challenging communication and language context. It is known that communication plays a key role in SE, with its significance for projects (Purna Sudhakar, 2012), individuals, and companies (Cress and Thomas, 2020). Communication is often considered a critical success factor (Purna Sudhakar, 2012) and failure in communication can prevent a team from achieving progress. Moreover, communication influences the productivity of software development (Canedo and Santos, 2019) and constitutes one of the six facets of teamwork quality (Hoegl and Gemuenden, 2001). In the context of global collaboration, interpersonal and communication skills belong to the most important skills in conjunction with proficiency in spoken and written language (Hidayati et al., 2020). Conversely, from the perspective of observed challenges in global development, language and cultural distance were identified as the greatest barriers (Noll et al., 2010) and they could be mitigated through training (Jain and Suman, 2015).

Competencies have been a subject of scientific research in SE. Competency models have been presented in a number of research papers that vary in focus and scope (e.g. Assyne et al., 2022a; Fernandez-Sanz, 2010; Moustroufas et al., 2015; Tagare et al., 2023). However, there appears to be a need to synthesize how the models approach competencies, their viewpoint and context, as well as how the models are developed and the competencies specified, considering, especially, the practical applicability. Furthermore, the role of intercultural communication in the international context is currently an interesting issue, with its presence and emphasis on the competency models being unclear. To gain an understanding of the needs, we conducted a Systematic Literature Review (SLR) that enables an overview of the extensive body of literature on SE competencies. This well-defined methodology (Kitchenham et al., 2016) facilitates the identification and analysis of the existing SE competency models and their construction. Through an SLR, the paper analyzes how international aspects are embedded in both the construction and content, and how intercultural communication aspects are embedded in the content of the models. The analysis focuses on how these aspects are represented, aiming to identify implications for SE education in the international context.

This study aims to identify and analyze existing SE competency models and their construction, as well as investigate communication, collaboration, intercultural, and language competencies embedded in these models. This scrutiny is conducted with a focus on the international aspects, to raise competencies required in the international SE context as a continuation of our prior study (Niva et al., 2023) or enable consideration of international aspects in the model construction process. This review is conducted through an international lens to highlight intercultural communication – especially through intercultural and language – competencies essential for international SE practice and to contribute to the development of models that better reflect international workplaces. In this paper, internationality refers to the workplaces where people from different nationalities and cultural and linguistic backgrounds collaborate within an organization's internal working environment and through international and global operations. In this respect, international and global competencies share the same premise on culturally and linguistically diverse collaborators, and are, hence, synonymized. Moreover, we have chosen to employ the term 'competency model' when addressing different compilations of competencies, competency frameworks, or profiles.

Through an extensive research process, 29 primary studies were identified for this review. By analyzing these studies, we provide an overview of SE competency models, their constructions, as well as international, communication, collaboration, intercultural, and language competencies embedded in these models. The paper highlights various elements influencing competency model construction. Moreover, we demonstrate that competency models and their construction lack international aspects in addition to that intercultural and language competencies are depreciated.

The rest of the paper is structured as follows. Section 2 describes the theoretical background, and Section 3 outlines the methodological choices. Section 4 presents the results. Section 5 discusses the findings and Section 6 discusses validity. Finally, Section 7 presents the conclusions.

2. Theoretical framework

Competencies are multifaceted and understood differently across various contexts. To contextualize our study, this section presents an overview of the general concepts that frame competency models in the international context. The concepts provide a solid theoretical background for this study, reflecting also model construction as well as international curricular guidelines and existing frameworks. To understand the competencies required in international workplaces, this section also explores international competencies that serve as a basis for international labor markets and workplaces.

2.1. General concepts

The terms 'competence' and 'competency' are often used interchangeably (Merriam-Webster, 2024) even though many stress that the terms are different. For example, Sanghi (2016) posits competence as skill-based and competency as behavior-based; however, the distinction is often ambiguous and not universally acknowledged. To elucidate this conceptual discrepancy, the subsequent paragraphs provide definitions for these and other central terms relevant to the study.

Competence refers to an individual's capacity (McConnell, 2001) or a qualification to perform (Sanghi, 2016). Job competence can be defined as "an employee's capacity to meet (or exceed) a job's requirements by producing the job outputs at an expected level of quality" (Dubois and Rothwell, 2000). Being competent means that the individual meets the requisite standards of the job (Dubois and Rothwell, 2000; Sanghi, 2016). Based on these definitions, competence can be seen as a measurable performance capability of an individual, related to a specific task or job and definable requirements.

Teodorescu (2006) states that competence models focus on clear and concise guidelines and define measurable, specific, and objective milestones an individual has to accomplish to meet or exceed the standards of the job. Competence models result in knowledge, skills, processes, and best practices required to support accomplishments (Teodorescu, 2006). Hence, competence models can be considered as the definable requirements of a task or job, which should, in practice, be measurable.

By contrast, competency can be regarded as an individual's behavior adopted in competent performance (Sanghi, 2016) or actual performance in a particular situation (McConnell, 2001). Job competency can

be defined as "an underlying characteristic of an employee that results in effective and/or superior performance" (Dubois and Rothwell, 2000). These tacit and explicit characteristics can address skills, knowledge, attributes, personal characteristics, desirable behavior, motives, traits, self-concepts, attitudes, values, aptitudes, abilities, social roles, and experience (Dubois and Rothwell, 2000; Kuruba, 2019; Sanghi, 2016; Teodorescu, 2006; Warner, 2012). In practice, competency is developed over time through work experience, training, and the practical application (Warner, 2012). Based on these definitions, competency is regarded as an inter-related set of individual – cognitive, emotional, and motivational – characteristics that enable successful performance in a particular situation.

The conceptual difference – competence addressing the requisite standards of the job and competency addressing individual behavior or characteristic in performance – can be reflected in the assessment of individual characteristics. While competence assessment focuses on potential knowledge and skills, competency assessment concerns the ability to perform, apply, and integrate knowledge and skills in a particular situation (McConnell, 2001). Both competence and competency models can be utilized for assessment, individual development, recruitment, and performance management in a work context (Dubois and Rothwell, 2000; Sanghi, 2016; Teodorescu, 2006). Competency models can additionally promote employee compensation and career development (Dubois and Rothwell, 2000).

In this study, given the broad perspective on individual capabilities, the concept of 'competency' is adopted as a key, composite concept. Competency models are considered and used as a means to specify competencies required in SE jobs and thus serve as a foundation for SE education. Competencies are considered and discussed within the international SE context.

2.2. Related work

This section delves into the international competencies that are explored through inter-related communication, collaboration, intercultural, and language competencies. Moreover, the section explores the construction of competency models, synthesizing insights from existing literature and international curricular guidelines and existing frameworks that serve as exemplary models for understanding the construction and application of competencies.

2.2.1. International competencies

International workplaces demand international competencies that are built on communication subjects (Ortiz-Marcos et al., 2020), i.e., on the forms of social interaction and behavior (Hargie, 2019a; Rickheit and Strohner, 2008). At the same time, international competencies rely fundamentally on cooperation in diverse team and multicultural environments, acceptance of differences and cultural knowledge, and communication in a foreign language; additionally, many other necessary competencies are built on them such as humility on the appreciation of the perspectives and world views of others, assertiveness on the respect for diversity while expressing opinions, self-awareness on sensitiveness how one's communication is interpreted, creativity on the perception of the world in new ways, and service-mindedness on collaboration and interaction with others (Ortiz-Marcos et al., 2020). Also, Warnick (2010) builds global competencies mainly on cross-cultural communication, working in an international team or transnational environment, and understanding of different cultures, as well as speaking more than one language.

Instead of considering communication in a foreign language only as one of the international competencies (Ortiz-Marcos et al., 2020; Warnick, 2010), Louhiala-Salminen and Kankaanranta (2011) go further saying that language is a key component in global communicative competence that is built on multicultural competence, English competence, and business know-how. Moreover, English proficiency plays a key role in the international workplace, and effective workplace communication in English is key to organizational and professional success (Rajprasit and Hemchua, 2015). The role of languages is also exhibited in intercultural communication competence that incorporates language proficiency in conjunction with cultural awareness and intercultural sensitivity, communication effectiveness, adaption, flexibility, empathy, and social integration (Sarwari et al., 2024). Also, the LESCANT model, representing key areas in intercultural communication, acknowledges the influence of language (L) alongside professional interaction (S), communication styles (C), leadership and decision-making (A), and non-verbal communication (N) on communication (Hernández Pozas et al., 2020).

These twisted perspectives on international competencies support the notion that language, culture, and communication are intertwined, interdependent, and interconnected (Gudykunst and Kim, 1992; Li, 2012) in addition to that communication can be considered the most elementary component of teamwork quality (Hoegl and Gemuenden, 2001). Moreover, culture is part of any communication activity (Chen, 2017) and shaped by language (Gudykunst and Kim, 1992; Li, 2012). The interconnected nature of competencies may obscure distinctions between them.

The decomposition of communication, collaboration, and intercultural competencies reveals a variety of topics that are beneficial to software practitioners. In addition to many aforementioned topics, professional practice requires communication design, explaining, discussions, receiving communication, nonverbal communication, presentations (Ruff and Carter, 2009), questioning, reinforcement, self-disclosure, listening, humor and laughter, and persuasion (Hargie, 2019b). On the other hand, collaborators are required to have adaptability to different cultures and environments, sociability, relation building, negotiation, encouragement and motivation, conflict management considering diversity and multiculturality, and leadership, as well as cultural knowledge and appreciation of cultural differences (Ortiz-Marcos et al., 2020). The extensiveness of these diverse competency requirements complicates the teaching landscape. Incorporating these competencies into the curriculum can, on the one hand, build the bridge between theoretical competency and practical application, and on the other hand, fill the skills gaps between the software industry and education.

According to Marnewick and Handley (2022), international competencies can be integrated into existing curricula by integrating soft and technical competencies. According to their competency-building model, more mature graduates can be educated through cyclic learning activities by integrating a technical knowledge area taken from the curriculum with one or more international competencies. Principally, this requires social learning and observations of other people's behaviors. First, learning at the individual level creates awareness and reflection. Secondly, learning in a team environment teaches diverse approaches, and thirdly, learning on the leadership dimension leads to optimal performance. Their model is based on five identified international competencies: communication, cognitive style awareness, culture awareness, ethics, and teamwork (Marnewick and Handley, 2022). Also, Akdur (2021) proposes that appropriate curriculum design can enable teaching soft competencies within technical courses.

In fact, Akdur (2021) proposes that there can be deficiencies in university education regarding oral and written communication and teamwork, with which recent graduates struggle (Radermacher et al., 2014). The existing challenges of effective communication with co-workers and customers (Radermacher et al., 2014) often fall short of meeting employers' requirements. Moreover, employers' requirements can be influenced by the context. According to (Niva et al., 2023), internationally operating employers require more communication, collaboration, intercultural, and English competencies than other employers. In fact, a large proportion of the internationally operating employers presented requirements for English proficiency and extensive and versatile collaboration competencies. Considerable demands were also presented for diverse communication competencies, whereas

intercultural competencies were almost ignored. The junior software engineers were largely required to have stakeholder, team, and project communication, collaboration practices, social skills, collaborative attitude, and independence. The rare cultural demands addressed to working in an international team and multicultural environment, as well as intercultural communication, tolerance, respect for others, knowledge of local working culture, global mindset, and adaptability. Furthermore, the employers presented requirements for a local native language, whereas the role of foreign languages other than English was minor (Niva et al., 2023).

Many of these requirements were also considered relevant to the SE practice in Matturro et al. (2019) whose mapping study on soft skills in SE identified 30 soft skill categories, with communication skills, teamwork, and interpersonal skills being among the five most frequently mentioned. Other most frequently mentioned skills comprised analytical, organizational, planning, leadership, problem-solving, autonomy, and decision-making skills. On the other hand, their study placed less emphasis on the ability to understand diversity, give and receive constructive criticism, cooperate with people of different races, entrepreneurship, moderation, diplomacy, rapport building, and coaching. Their results almost left intercultural competencies and language proficiency unaddressed (Matturro et al., 2019).

2.2.2. Constructing competency models

Competencies may not be easily measurable as they can be broad, subjective, high-level, and not directly observable in performance (Teodorescu, 2006). In fact, Pikkarainen (2014) compares performance to an iceberg whose visible peak changes according to the environment. Moreover, competencies can be shared, private, or inter-related (Frezza et al., 2018). Many relevant characteristics can be hidden, deeper, and central to personality and thus more difficult to assess, measure, and develop, contrary to knowledge and skills that are most visible and relatively easy to develop and measure (Sanghi, 2016). In fact, collection of competencies can also be influenced by conceptual fragmentation, observed as variation in fundamental concepts and chosen viewpoints (Pikkarainen, 2014).

Developing a competency model requires familiarization with job tasks, activities, and outputs (Dubois and Rothwell, 2000) and can be based on different data collection methods. Competency identification can rely on interviews, focus groups, observations, questionnaires, surveys (Dubois and Rothwell, 2000; Sanghi, 2016) conducted among the industry, employees, teams, supervisors, customers, and suppliers (Sanghi, 2016). Moreover, competencies can be pinpointed from diaries, laws, regulations, union contracts, certification requirements, quality standards, academic journals, publications, and periodicals, as well as from the organization and its vision, mission, manuals, flowcharts, planning documents, appraisal forms, and training calendar (Sanghi, 2016). Competencies can also be pursued by benchmarking (Sanghi, 2016). Moreover, a competency model can be adopted or tailored from an existing model (Dubois and Rothwell, 2000; Sanghi, 2016) or be built on an existing competency list or dictionary (Dubois and Rothwell, 2000).

Depending on the needs or purpose of the use, competency models can be built either on threshold competencies, essential to all individuals successfully producing the expected job outputs, or differentiating competencies distinguishing superior performers from average (Dubois and Rothwell, 2000; Sanghi, 2016). Moreover, competencies can structurally be divided into different categories, such as technical and personal functioning (Dubois and Rothwell, 2000), technical and behavioral (Kuruba, 2019), or core, generic, and role-specific competencies (Warner, 2012). Furthermore, competencies can be built as a pyramid where the upper-level industry, occupation-specific, and management competencies are built on the foundational, lower-level personal effectiveness, academic, and workplace competencies (U.S. Department of Labor, 2017, n.d.).

Competencies and skills have been covered in prior SE literature. According to Matturro et al.'s (2019) systematic mapping study, soft skills were identified through various data collection methods including job ads, survey, literature review, interview, focus group, and experiment. However, their results disregarded the details involved in constructing a comprehensive competency model. Secondly, Assyne et al.'s (2022b) systematic mapping study on SE competencies provided a valuable foundation by identifying 14 SE competency models; the utilization of their study as part of pre-study in this SLR is described in Section 3.1. Nonetheless, these studies did not address the specific research questions guiding this review, particularly those related to international aspects and the inclusion of intercultural and language competencies.

2.2.3. International curricular guidelines and existing frameworks

International consortia and organizations develop common guidelines, best practices, and bodies of knowledge that are necessary for practitioners and can be integrated into education. This section examines key curricular guidelines and frameworks suitable to SE, emphasizing their structural characteristics and international competencies.

2.2.3.1. e-CF. The European e-Competence Framework (e-CF) (ICT-mastery.eu, n.d.; IT Professionalism Europe, n.d.) defines competences for ICT professionals, focusing on technical competences. The framework is built on four dimensions, of which the first defines five e-competence areas (Plan, Build, Run, Enable, Manage), the second 41 e-competences (such as Application Development), the third five proficiency levels (e-1 to e-5 related to EQF levels 3 to 8), and the fourth examples of knowledge and skills. This framework can bridge the gap between the supply and demand of ICT skills, fostering a more competitive and digitally competent European workforce.

To be used as a foundation for a competency model, the e-CF (ICT-mastery.eu, n.d.) specifies proficiency levels, for example, for application development: at level 1, an individual acts under guidance, at level 2 systematically develops and validates applications, and at level 3 acts creatively to develop applications. According to dimension 4, the individual must, from the perspective of skills, be able to explain and communicate the design and development to the customer and cooperate with the development team and with application designers and possess knowledge, for example, about appropriate software programs / modules, programming languages, and security.

2.2.3.2. ESCO. Another framework that can be applied when building a competency model is European Skills, Competences, Qualifications, and Occupations (ESCO) (European Commission, n.d.; n.d., n.d.) that is a dictionary for knowledge, skills, and competences relevant to the European labor market. ESCO's skills pillar is structured under four sub-classifications: knowledge; language skills and knowledge; skills; and transversal skills.

According to ESCO (European Commission, n.d.), a software developer should possess a diverse set of essential and optional knowledge, skills, and competences, including mainly a wide range of technical competencies such as computer programming and engineering principles. According to ESCO, an individual needs skills and competences for working with computers, but also communication, collaboration, and creativity; information skills; and management skills. ESCO makes no distinction between skills and competences.

2.2.3.3. SWECOM. The Software Engineering Competency Model (SWECOM) (IEEE Computer Society, 2014) describes competencies, i.e., demonstrated abilities for software engineers who develop and modify software-intensive systems. The model specifies skill areas, skills, and work activities that are specified at five levels of competency utilizing the verbs: follow (F), assist (A), perform (P), lead (L), and create (C). According to the model, cognitive skills and behavioral attributes and skills are applied at all levels of technical skill areas, skills, and activities,

even though they are not specified by competence level. SWECOM regards cognitive skills and behavioral attributes and skills as necessary for effective performance, whereas requisite knowledge forms the intellectual basis. Structurally, SWECOM covers technical skills, cognitive skills, behavioral attributes and skills, requisite knowledge, and related disciplines.

To exemplify the content of SWECOM (IEEE Computer Society, 2014), the software construction skill area includes skill sets such as software construction planning, detailed design and coding, and integrating and collaborating. Each skill set is specified by competency levels. For example, in integration and collaboration, an entry-level practitioner collaborates with other team members in development activities (P), whereas a senior software engineer creates new integration tools and processes (C). Other examples of SWECOM specifications include reasoning, analytical skills, and problem-solving as cognitive skills and computer science, mathematics, and project management as related disciplines.

Correspondingly, SWECOM (IEEE Computer Society, 2014) exemplifies some behavioral attributes and skills while acknowledging that other behavioral attributes and skills could be added. These examples include communication skills, team participation skills, and cultural sensitivity. Communication skills cover expressing oneself in both oral and written forms clearly and concisely while interacting with team members, managers, and other stakeholders in conjunction with effective listening. Team participation skills are demonstrated "by working enthusiastically and willingly with other team members while collaborating on shared tasks." Moreover, the attribute of cultural sensitivity concerns "an awareness of and accommodation for differences in communication styles, social interactions, dress codes, and overall behavior based on ethnic, religious, gender orientation, and other behavioral characteristics." Otherwise, cultural competency is covered as international accessibility, languages, and cultural considerations in the human-computer interaction skills area.

2.2.3.4. SE2014. Curriculum Guidelines for Undergraduate Degree Programs in Software Engineering (SE2014) (IEEE Computer Society and ACM, 2015) provide a foundation for an SE curriculum based on a three-level hierarchical structure: knowledge areas (KA), units, and topics. Hierarchically, each KA, i.e., a subdiscipline is decomposed into units, i.e., thematic modules, including the recommended number of contact hours, and are further subdivided into topics. Moreover, each topic is specified first, by the cognitive skills level, either as knowledge (k), comprehension (c), or application (a), and second, by relevance, either as essential (E) or desirable (D). To exemplify the contents of SE2014, KAs include software design, mathematical and engineering fundamentals, and software quality. Among the ten KAs, there is a KA of professional practice that covers group dynamics and psychology, communication skills, and professionalism.

Despite the strong prevalence of technical knowledge areas, SE2014 (IEEE Computer Society and ACM, 2015) regards that interpersonal relations play a central role in many SE activities. According to SE2014, graduates should communicate efficiently in all contexts, in writing, when giving presentations and demonstrating software, and in discussions, as well as be able to work both individually and as part of a team and acknowledge the importance of negotiation, leadership, and good communication with stakeholders. Students should also develop listening. In practice, the group dynamics and psychology unit includes topics such as dynamics of working in teams and groups (a), interacting with stakeholders (c), and dealing with multicultural environments (k) whereas the unit of communication skills includes reading, understanding, and summarizing reading (a); writing (a); team and group communication (a); and presentation skills (a). All these topics were considered essential.

2.2.3.5. CC2020. Computing Curricula 2020 (CC2020) (ACM and IEEE Computer Society, 2020) is a competency framework that provides curricular guidelines for computing education. CC2020 is built on competencies, i.e., the qualities an individual must possess to be effective in a job, role, function, task, or duty, and consists of knowledge, skills, and dispositions observed in the performance of a task. CC2020 also covers an undergraduate program in SE.

According to CC2020 (ACM and IEEE Computer Society, 2020), knowledge refers to factual understanding, subject matters, and core concepts consisting of both computing knowledge; and foundational and professional knowledge. There are six categories within technical computing knowledge, including, for example, software development and software fundamentals. To reflect the relative importance of the technical knowledge area, CC2020 introduces a numeric scale, 1 to 5, to specify a minimum and maximum value, suggesting an importance range within six disciplines, of which SE is one. Correspondingly, there are thirteen elements in foundational and professional knowledge, including collaboration and teamwork, oral communication and presentation for real-time presentations, and written communication as a form of interaction in messaging.

Regarding the other competency elements, CC2020 (ACM and IEEE Computer Society, 2020) defines skills as "the capability of applying knowledge to actively accomplish a task, "referring to six levels of cognitive skills: remembering, understanding, applying, analyzing, evaluating, and creating. To define qualities required for task performance, CC2020 is built on dispositions that moderate the behavior of applying knowledge that becomes a skill, and which include intellectual, social, socio-emotional, or moral tendencies, habitual inclinations, predilections, and attitudes. These eleven prospective dispositions include, for example, adaptability, an ability to collaborate, proactivity, professionalism, and self-directedness. Furthermore, CC2020 addresses globality surrounding computing education and regards universal acceptance of global diversity and cultural sensitivity as essential in all fields of endeavor. 'Cultural sensitivity and diversity' is one of the areas in professionalism and ethics that, according to CC2020, should be a permanent element of any computing curriculum. CC2020 highlights that "it is important to be aware that cultural similarities and differences do exist between people and the computing programs they represent."

2.2.3.6. SWEBOK. Software Engineering Body of Knowledge v4.0 (SWEBOK) (IEEE Computer Society, 2024) characterizes the content of the SE discipline and aims at providing a foundation for curriculum development. The content is organized into 18, mainly technical, knowledge areas (KA) that are characterized and decomposed into subtopics. The knowledge area of SE professional practice covers professionalism, group dynamics and psychology, and communication skills, including dynamics of working in teams and groups, interacting with stakeholders, dealing with equity, diversity, and inclusivity; reading, understanding and summarizing; writing, team and group communication; and presentation skills.

SWEBOK (IEEE Computer Society, 2024) specifies that a software engineer needs to be able to work with others, internally in teams, but also with customers and other stakeholders. Collaborative competencies expect shared outcomes, shared responsibilities, cohesion, aligned goals, respect, and information sharing. Moreover, a software engineer is expected to communicate clearly, directly and in documents, orally and in writing, maintain communication and face-to-face interaction. Working requires writing clearly, concisely, understandably, and for an intended audience. Moreover, a software engineer should manage documentation and emails and be able to train, explain, consult, and solicit ideas or feedback. Moreover, the software engineer needs to investigate, comprehend, and summarize information; read; make decisions; provide and receive information and feedback; and give presentations.

SWEBOK (IEEE Computer Society, 2024) acknowledges that work commonly takes place in teams consisting of people from diverse cultural backgrounds and in multicultural environments. Success requires team members to embrace tolerance of different cultural and social norms. Cultural differences may affect the team. On the other hand, SWEBOK points out that cultural divisions can be mitigated by more frequent communication. Linguistically, SWEBOK determines that team communication in the native language could be beneficial.

3. Methodology

This study has been undertaken as a systematic literature review (SLR), by applying the guidelines presented in Kitchenham et al. (2016). The SLR aims to provide an objective approach for finding relevant primary studies, as well as for extracting, aggregating, and synthesizing the data (Kitchenham et al., 2016). The SLR is based on "a well-defined methodology to identify, analyze, and interpret all available evidence related to a specific research question in a way that is unbiased and (to a degree) repeatable" (Kitchenham, 2007). The stages of this SLR process included planning, pre-study, selecting studies, screening pilot, actual screening steps, quality assessment, data extraction, synthesis, and documenting. Rather than conducting a mapping study, which aims to provide an overview of the scope of the research area (Petersen et al., 2015), this study gathers and synthesizes more extensive evidence relating to the content and construction of the competency models.

This study began with a planning stage that included familiarization with the existing literature used to frame the study within the variety of multiple concepts used in the context of similar studies. The exploration of prior research revealed a body of research conducted on the same area, as well as a good-quality review addressing a similar topic. The scrutiny of existing SE research revealed that the papers, however, lacked a thorough investigation of communication, collaboration, intercultural, and language competencies, as well as a comprehensive overview of the competency model construction. However, the systematic mapping study conducted by Assyne et al. (2022b) provided a sound basis and was utilized in the pre-study. In this stage, the review protocol was also initiated, based on the application of guidelines in Kitchenham et al. (2016), however, tailored to correspond to the practical steps of the research process. The protocol was updated and validated in discussions with and by two experienced researchers, the second and third author of the paper.

Pre-study comprised a rigorous scrutiny of the study of Assyne et al. (2022b) whose systematic mapping study on SE competencies established a sound basis for competency model search and the initiation of the search criteria. The inspection, completed with MS Excel and NVivo, resulted in 5 competency models identified by Assyne et al. (2022b) that aligned with the scope of this study and were, thus, chosen for the study, to be verified in the quality assessment phase together with the studies found in the actual SLR process. Secondly, these five articles were utilized as a basis for the final search string. The terminology employed within these five articles' title, abstract, or keyword fields included different occurrences of software-initiated terms; all the articles included a software-related term, such as software development, software industry, and software product. The analysis also revealed that the word 'competency' or its variation 'competence,' 'competences,' or 'competencies' appeared in all the articles. Moreover, four of the articles referred to either 'skill' or 'skills.' Furthermore, all five articles included either 'model' or 'framework' in addition to that one paper referred to the concept of 'profile.' These identified terms were incorporated into the formulation stage of the final search string.

3.1. Review questions

The formulation of the research questions was based on the aim to identify SE-associated comprehensive compilations of competencies that are requisite at a particular stage of the software lifecycle or at a particular stage of the software practitioner's professional career and that provide a holistic view on individually attainable competencies that need to be embodied, acquired, learned, or taught for success or higher performance. Enabling the focus on communication, collaboration, intercultural, and language competencies led to an underlying prerequisite for selection mandating the incorporation of soft competencies. In practice, it was expected that these compilations comprise different SE competency models, competency frameworks, skill profiles, curricula, syllabi, learning contents, and other collections of competencies presented using a variety of textual and graphic formats encompassing any characteristic of competency, competence, skill, ability, attribute, knowledge, disposition, or capability.

The review aimed at addressing the following research questions (RQ):

RQ1: What purposes have competency models been created for?
RQ2: What communication, collaboration, intercultural, and language competencies have been identified?
RQ3: How have competency models been constructed?

RQ1 enhances our understanding of the goals and potential benefits associated with the development of competency models. While RQ1 depicts why competency models are constructed, RQ3 offers insights into how they are constructed, emphasizing methodological, conceptual, and representation aspects. RQ2 delves into the competencies required in international workplaces. In addition to international competencies, RQ2 increases understanding of the significance of communication, collaboration, intercultural, and language competencies in SE. Collectively, these RQs facilitate the examination of the international aspects within the competency models and in their construction process.

3.2. Data sources and search strategy

The study selection stage involved choosing databases, developing the search string, defining inclusion and exclusion criteria, and implementing the search. In this step, the following electronic databases were chosen due to their extensive coverage of SE topics: the ACM Digital Library, IEEE Xplore, Scopus, and Web of Science. After selecting databases, the search string was developed relying on thorough testing, as illustrated in Appendix A. Generally, the search aimed at a sufficiently large search result to mitigate the effect of the low number of SE competence models identified in Assyne et al.'s (2022b)'s mapping study (0.11 %) and own pilot searches.

First, it emerged that the search terms 'competenc* model,' 'competenc* framework,' 'competenc* profile,' 'skill* model,' and 'skill* framework' produced occurrences, whereas the word 'outline' was rarely used and was, thus, omitted. However, despite the numerous search results, the inspection of potential and pre-study papers revealed that several potential primary studies can be omitted with these combined search strings. Hence, the search phrases were split into two separate competency- and model-related parts. At this point, the synonyms for the words 'competency' and 'model' were examined. For example, the word 'capability' was omitted due to a substantial increase in the articles referring to capability maturity models that fall outside the intended scope. Secondly, the search string must produce items related to SE, software development (SD), the stages of the software life cycle, and the stages of the software practitioner's career, as well as various job titles. Thirdly, the search string was finalized for singular and plural forms as well as for derivatives using the asterisk '*'. The final search string consisted of three parts:

("software develop" OR "software engineer*" OR "software industr*" OR "software organization*" OR "software process*" OR "software product*" OR "software project*" OR "software test*" OR "software design*" OR "software analys*" OR "software team*" OR "software compan*" OR "software firm*" OR "software house*" OR "software system*")*

Table 1
Inclusion and Exclusion Criteria.

Inclusion Criteria	Exclusion Criteria
1 The study pertains to the field of SE or addresses SD (activity, tasks, job role).	1 The study concerns teaching a single course or subject matter.
2 The study identifies more than one individual competency or describes a kind of competency model (framework, profile) or describes a curriculum.	2 The study focuses on organizational competencies.
3 The study proposes a competency model.	3 The study does not propose a competency model, proposes a model other than a competency model, or proposes a model that is not a result of the study.
4 The model captures a collection of soft competencies.	4 The model includes fewer than five soft competencies.
5 The study answers the research questions	
6 The paper must be peer-reviewed	
7 The paper must be written in English	

AND

("competenc" OR "skill*")*

AND

(model OR framework OR profile)

The search string was employed in the selected databases to search within the article title, abstract, and keywords from 2010 to 2024. The time frame includes the period (from 2010 to 2013) during which the models chosen in the pre-study were published and extended to 2024. Document types were limited to articles, conference papers, and book chapters. The search criteria were adjusted separately for each database.

To identify the studies that provide evidence for research questions, inclusion and exclusion criteria were developed. The inclusion and exclusion criteria are presented in Table 1.

All the chosen studies must meet all the inclusion criteria. Firstly, the study must relate to the SE field or address SD work. The criterion grasps software-related terms, such as software project and software industry, as well as software lifecycle-related job titles, such as software analyst, tester, or designer. Secondly, the study must address competency, competence, skill, ability, knowledge, or any other subordinate to competency that are necessary for high performance, success, work requirements, proficiency, qualification, mastery, capability, or expertise. This criterion grasps studies that report on competencies, competency models or profiles, other collections of competencies, in addition to curricula, syllabi, and learning contents. Thirdly, the study must propose a competency model that is a result of the study. Fourthly, the proposed competency model must include at least five soft competencies. Competency models containing fewer than 5 soft competencies were deemed to place considerable emphasis on technical competencies and were, thus, excluded, while this study aims to analyze models with a central focus on soft, intercultural communication competencies. In the end, the paper must also be peer-reviewed and written in English.

These criteria attempted to eliminate studies on teaching a single course or subject matter, organizational competencies, models other than competency models, as well as the competency models focusing mainly on technical competencies. Teaching a single course or subject matter was not conceived to produce a holistic view on competencies. Moreover, the models including fewer than five soft competencies were regarded as too simplistic for the purposes of the study. Also, prior versions of the selected papers and those with essential model parts stored externally were eliminated. In the end, the chosen studies must answer the research questions. These answers were also derived from secondary SLR studies that were not excluded by the criteria to ensure comprehensive coverage of the research topic. In practice, title and abstract screening stages were based on the inclusion and exclusion criteria 1 and 2, whereas the final selection of papers in full-text screening was based on all the inclusion and exclusion criteria.

To improve a shared understanding of inclusion and exclusion criteria between the authors, we conducted title and abstract screening pilots before the actual screening process. Based on these separately implemented screening pilots, inclusion and exclusion criteria were updated and discussed. The pilot facilitated discussions and agreements regarding the use, features, and user interface settings of Covidence and their implications for the screening task.

3.3. Screening

The screening process covered three sequential steps: title screening, abstract screening, and full-text screening. Moreover, full-text screening comprised both model skimming and full-text reading.

Title Screening was based on the inclusion and exclusion criteria 1 and 2 (Table 1). Detecting the inclusion of the model, as stated in inclusion criterion 3, based on a title was impossible, and thus ignored, as well as other criteria. In uncertain cases when the title was not descriptive enough, a journal or conference name was used in decision-making as agreed in the pilot, due to the visibility of a journal or conference name in the Covidence user interface without options to hide. This information occasionally served as a disciplinary indicator, helping to identify and exclude studies originating from distant disciplines, such as medicine, considered irrelevant to the scope of the review.

Each study was screened by at least two researchers. The screening process was distributed among the authors as follows: the first author was responsible for independently screening all studies. In parallel, the second and third authors jointly shared the screening task by dividing the dataset between them. In cases where the screening decisions were conflicting, the study was screened the third time by either the second or third author who had not voted for the paper in question yet.

In practice, Covidence provides three options for screening: yes, maybe, and no. According to Covidence's voting rules, a paper was moved to the next phase if two screeners had chosen 'yes' or 'maybe.' In case, one author chose 'yes' or 'maybe' and the other 'no,' then the paper was moved to conflict resolution, to be screened the third time. Then, the final decision regarding inclusion or exclusion was made by the screener who had not voted yet for the paper in question.

Abstract Screening was conducted in Covidence using the same inclusion and exclusion criteria 1 and 2 applied during title screening. Each study was screened by at least two authors. The screening responsibilities were distributed similarly to the title screening: the first author independently screened all studies, while the second and third authors divided the dataset between them. In cases of conflicting decisions, the study was reviewed by the author who had not previously voted on it.

The full-text screening was conducted by MS Excel, with the assistance of Covidence and Zotero. Covidence was used, at first, to bulk upload missing full texts. The full texts were also searched in Zotero, after exporting the references from Covidence to Zotero. Moreover, the first author searched the full texts manually using electronic databases offered by the university library, Google, and Google Scholar.

In practice, full-text screening was completed in two steps: model skimming and full-text reading. First, the first author scanned all the articles focusing on the models. The articles lacking a competency model were excluded based on inclusion and exclusion criteria 3. Second, in full-text reading, the articles were read in full and analyzed carefully by the first author. All the inclusion and exclusion criteria were used in this step.

The results of full-text screening were validated through collaborative discussions. The first author presented the results of both model skimming and full-text reading steps to other authors, including detailed explanations of the decisions made and the criteria applied. During the discussions, the authors reviewed the decisions made considering the inclusion and exclusion criteria, and the issues were addressed

Table 2
Quality checklist.

Question
Is the paper based on research (or is it merely a 'lessons learned' report based on expert opinion)?
Is there a clear statement of the aims of the research?
Is there an adequate description of the context in which the research was carried out?
Was the research design appropriate to address the aims of the research?
Was the recruitment strategy appropriate to the aims of the research?
Was the data collected in a way that addressed the research issue?
Was the data analysis sufficiently rigorous?
Has the relationship between researcher and participants been adequately considered?
Is there a clear statement of findings?
Is the study of value for research or practice?

Table 3
Extracted Data.

Need	fields
Overview of the studies	publication details, name of the conference, name of the journal, publication year, database
For RQ1	application domain, name of the model, aim of the model, role of the model in the study, job roles, use scenarios, international aspects
For RQ2	international competency, communication competency, collaboration and teamwork competency, intercultural competency, native language competency, English language competency for each: expertise level, position among soft competencies, supplementary
For RQ3	conceptual basis, definition of the main competency concept, type of competency, hard and/or soft, competency categories, level of expertise, place of competency description, research method, research strategy, data collection methods, data source, origin of competencies, analysis methods, phases of the study, appearance, international aspects
For RQ1-RQ3	screen capture of competency model

collaboratively. Finally, the authors reached a final agreement on the studies included in the quality assessment.

3.4. Quality assessment

The quality of the selected papers was assessed by a quality checklist appropriate for multiple study types. The quality assessment applied the questions of Dybå & Dingsour (2008) as presented in Kitchenham et al. (2016). Of the eleven suggested criteria, one question, control group comparison, was ignored due to its irrelevance to the study. The questions are presented in Table 2.

The scoring of the studies was completed with ten quality checklist questions using the scale: yes = 1, partly = 0.5, and no = 0. Hence, the maximum score is 10 points. The quality assessment was completed by the first author for studies chosen either in pre-study or full-text screening.

The results of the quality assessment were validated through collaborative discussions. The first author presented the assessment procedure to the other authors. During the discussions, the issues were addressed collaboratively. Finally, the authors reached a final agreement on the application of the quality criteria.

The articles with a score greater than or equal to 6.5 were included in the study. This threshold was selected to ensure the inclusion of a sufficient number of high-quality primary studies while maintaining the overall reliability of the study. The primary studies scoring clearly below this threshold reflected insufficient methodological detail, whereas borderline cases were excluded as the final set of 29 included papers deemed adequate in size.

3.5. Data extraction and synthesis

Data extraction was completed to gather relevant information for aggregation and synthesis. Extracted data is displayed in Table 3.

Data extraction involved identifying relevant textual segments from the papers to gather information for aggregation and qualitative synthesis. When information was not explicitly stated, the text was interpreted accordingly. Following this, the data was meticulously reviewed and categorized to ensure comprehensive coverage of each research question. Moreover, data extraction covered screen captures of the competency models. In practice, synthesis was conducted through an iterative process, involving both extracted data and visual documentation, i.e., screen captures of the competency models.

For an overview of studies, publication details were extracted from each paper. The selected papers were characterized by descriptive statistics.

In RQ1, data extraction covered model-specific attributes such as the application domain, model name, aims, and job roles included in the competency model. The analysis also required contextual information regarding the role of the competency model within the primary study, described and implied use scenarios, and involved international aspects. SWEBOK knowledge areas (IEEE Computer Society, 2024) were primarily used as a classification framework for application domains while areas not covered by SWEBOK were classified under specific and limited domains. Otherwise, synthesis was completed inductively.

Throughout all the RQs, the analysis was based on content analysis and thematic synthesis methods. Content analysis was used to categorize data and determine the frequency of the categories (Dekkers et al., 2022) whereas thematic synthesis relied on the identification and coding of the recurrent themes and summarizing the results under thematic headings (Kitchenham et al., 2016).

For RQ2, data extraction was completed separately for each thematic competency area, guided by definitions and classifications provided in Niva et al. (2023). For international competencies, only items with explicit references to international aspects were considered.

The main extraction process encompassed all relevant competency labels, their definitions and descriptions, as well as associated expertise levels and highest positions among other soft competencies. Data extraction primarily focused on the items represented within the competency models; however, supplementary textual data were also collected in cases when a specific competency was omitted from the model but appeared in data or text.

Each thematic area was coded and analyzed using content and thematic analysis. The synthesis focused on how these areas were represented, either as high-level constructs or through multiple related competencies and sub-competencies – an aspect also addressed by granularity under RQ3. Moreover, to enhance the practical applicability of the findings – particularly to offer input for educational content design, individual components of each thematic competency area were inductively identified and collected. This process involved organizing the 'in vivo' components into thematic categories.

For RQ3, most data were coded and analyzed inductively. However, concepts of competence and competency, and their (sub)characteristics as described in Related Work (Dubois and Rothwell, 2000; Kuruba, 2019; McConnell, 2001; Sanghi, 2016; Teodorescu, 2006; Warner, 2012) were used as a framework for the conceptual basis. The coding of the research methods, research strategies, data collection methods, and analysis methods was mainly based on (Saunders et al., 2016). However, the term 'survey' was equated with 'questionnaire' but treated separately; the Delphi method was added to strategies (Pickard, 2013); primary data collection methods were extended by document secondary data (Saunders et al., 2016) defined inductively; and the categories of quantitative analysis methods relied on Devore and Peck (2005). In addition to the pre-defined categories, the analysis identified additional classes that were derived inductively from the papers.

To determine the sources of data used to build a competency model, data extraction encompassed two fields: data source and origin of competencies. Data source comprised the identification of subjects, i.e., participants in an empirical study and written sources, i.e., existing

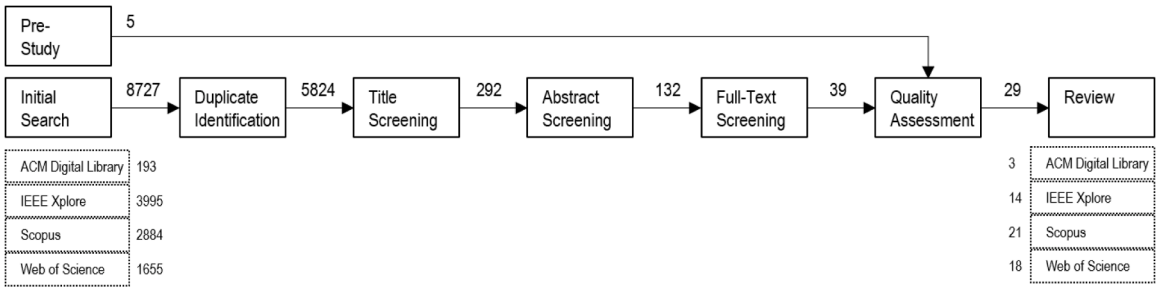

Fig. 1. Selection process.

literature. The origin of competencies was determined through the methods utilized in data collection. The level of granularity, reflecting the degree of detail with which competencies and expectations were defined or described within each model, was analyzed based on data extracted for RQ2, using communication as a case competency due to its central role in a study and its prevalence across the identified models. The phases of the studies, including the sequence and implementation of data collection steps, were extracted and analyzed to understand the progression within the primary studies. The appearances of the model were inductively classified. Moreover, all representation types were visually exemplified in a graphic model library – illustrating also what was considered as a competency model in this study.

Data extraction and synthesis were completed manually by the first author and validated through collaborative author discussions. The primary data extraction and synthesis conducted by MS Excel was supported by NVivo.

To facilitate reproducibility, a GitHub repository (https://github.com/anujniva/secompetencymodels) contains material, including the research aim and questions, data sources, search string, inclusion and exclusion criteria, quality assessment criteria, list of selected papers, list of variables in data extraction, as well as the data extraction file. The file contains a single filled row exemplifying the data extraction process applied to one paper.

4. Results

This section presents the results of the analysis of 29 primary studies, each of which includes a SE competency model. The results are described based on the research questions. Moreover, the overall coverage of choices relevant to the model construction based on RQ1 and RQ3 is collected in Table 13.

4.1. Overview of studies

The progression of the study is illustrated in Fig. 1.

Pre-study resulted in 5 competency models that aligned with the scope of this study. These papers were approved for quality assessment with the primary studies identified in the actual SLR process. The selection of the primary studies with the search string generated an initial set of 8727 papers queried from four digital databases. The literature search was conducted on 20th January 2024. After filtering duplicate papers, 5824 papers were left for further processing. Title screening condensed this dataset to 292 papers (the Kappa value 0.2589, prior to conflict resolutions) and subsequently, abstract screening to 132 papers (the Kappa value 0.3655). In full-text screening, model scanning resulted in 58 papers, from which, after full-text reading, 39 papers were approved for quality assessment. The final set of primary studies includes 29 papers.

A substantial proportion of the selected 29 primary studies were indexed in multiple databases, as illustrated in Fig. 1. Scopus (21), Web of Science (18), and IEEE Explore (14) were the most comprehensive sources for this research topic, whereas the role of the ACM Digital Library (3) demonstrates more limited coverage. Of these studies, 14 were published in journals and 15 in conferences that are listed in Appendix B. Of the journal publications, 3 were published in IEEE Access and 2 in Information and Software Technology. Correspondingly, 2 of the conference publications were published in the IEEE Global Engineering Education Conference, whereas the remaining conferences had one paper each. All the selected papers were published between 2010 and 2023, as presented in Fig. 2.

The publications spread evenly between 2010 and 2020, with 1 or 2 publications per year, except for the year 2015, during which no publication was listed. In recent years, the number of publications appears to have increased. A considerable set of the selected primary studies (12) were published in three years between 2021 and 2023.

Regarding conferences, the publications spread consistently between 2010 and 2023, with an annual output ranging from 0 to 2. In journal publications from 2011 to 2023, the highest number of publications was 4 in 2022. Otherwise, the number of journal publications per year remained at 1 or 2, with no publications recorded between 2015 and 2018, and 2020. The selected studies are listed in Appendix C.

4.2. Purposes of competency models

Competency models vary in content across various application domains and serve different purposes. They occupy various roles in studies and facilitate multiple use scenarios. Competency models are predominantly created to encompass both technical and soft competencies, as evidenced by 28 of 29 models that include both technical and soft competencies. In contrast, models dedicated solely to soft competencies are rare, with only 1 competency model [P9].

Generally, competency models serve different functions in various studies. In most primary papers (16), the construction of the competency model constituted the main goal of the paper [P1, P3, P4, P5, P6, P7, P8, P9, P10, P16, P17, P18, P22, P24, P25, P29]. Otherwise, competency models were parts of the larger investigations of job market demands [P11, P12, P15, P19, P20, P21, P26], results of SLR [P14, P23], parts of the analysis of the gaps between industry and academia [P27, P28], part

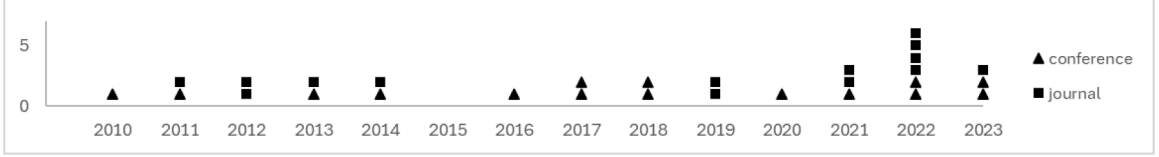

Fig. 2. Overview of the publication years by publication channels.

Table 4
Application Domains.

Application Domain	Count	Primary studies
GENERAL DOMAIN		
Software Engineering	8	P1*, P2*, P9, P22, P23, P24, P27, P29
KNOWLEDGE AREA SPECIFIC		
Software Requirements	3	P4, P11, P12
Software Testing	2	P5*, P20
Software Management	2	P16, P28
Software Quality	1	P3*
RELATED DISCIPLINES		
Computer Science	2	P7, P13
Project Management	1	P21
SPECIFIC OR LIMITED DOMAIN		
Agile Development	4	P8, P14, P18*, P25*
Open Source	2	P6, P26
Entrepreneurship	2	P10, P17
Big Data	1	P15
Blockchain	1	P19
Grand Total	**29**	

* Competency model provides a view on competencies from the perspective of several job roles.

of the larger model [P2], or result from framework demonstration [P13]. Even though competency models are primarily constructed as the main goals of the study, they also play a secondary role in more extensive research endeavors.

Competency models vary in their focus area. While some competency models provide a general, holistic view of SE competencies, others focus on competencies pertinent to specific and limited knowledge areas, domains, or related disciplines. The application domains are presented in Table 4.

Competency models encompass SE across various domains. Some models pertain to the entire field, such as 'competency framework for software engineers' [P1], whereas some address more specific and limited application domains. In all, 8 of the models can be connected to specific SWEBOK knowledge areas (IEEE Computer Society, 2024) such as a competence model for testing teams [P5] and a competency model for requirements analysts [P4]. Beyond the models addressing software requirements, testing, management, and quality, 3 competency models address related disciplines, computer science, or project management, such as Project Manager Competencies [P21]. All application domains, however, do not align with the classification of SWEBOK.

Regarding application domains, there were 4 competency models [P8, P14, P18*, P25] that examined competencies from the perspective of agile development, i.e., a topic integrated into almost all knowledge areas in SWEBOK (IEEE Computer Society, 2024). Moreover, a model can be connected to a specific job role, such as 'a competency model for customer representatives in agile software development projects' [P8]. Furthermore, 4 models were constructed for specific or limited software domains such as open source [P6, P26], big data [P15], and blockchain [P19]. Competencies were also analyzed from the perspective of entrepreneurship [P10, P17].

As marked with an asterisk in Table 4, only 6 competency models define competency requirements for a set of various job roles. For example, 2 models, assigned to the general SE domain [P1, P2], specify the required levels of expertise, for example, for the roles of project manager, analyst, designer, programmer, tester, and documenter. Moreover, there are models that provide competencies specified by expertise levels for job roles in agile development, testing, and software process improvement.

Regarding explicit characteristics, internationality is no predominant characteristic in the context of the competency model. Only 2 competency models have an international focus. One study [P25] focused on Scrum team competencies in the global software development environment, and the other [P11] on comparing job market demands between two countries. Otherwise, internationality was not explicitly emphasized in aims and contexts.

4.2.1. Practical use scenarios

The analysis of the fundamental motives behind the construction of the competency models uncovers a multifaceted set of aims and objectives of the studies and models, implications, contributions, and practical use scenarios. The studies rely mostly on practical motives for enhancing industry, but many also prioritize academia and knowledge. Typically, the studies emphasized use scenarios for multiple beneficiaries. For example, education was the primary focus of 6 studies — 4 [P7, P9, P24, P29] through the construction of the competency model for educational purposes, and 2 [P27, P28] by analyzing the skill gap between industry and academia. In the end, about half of the studies reported on educational use scenarios. The following two extracts illustrate a primary and secondary weight given for educational purposes:

> *The results of our research will be the basis for measuring competencies — and for developing university education —. SWEBOS [the competency model] is intended to lay a basis for a teaching goal- and competency-oriented approach. [P9]*

> *The model may provide a preliminary guidance for competencies development of entrepreneurs in software industries. The entrepreneurs in software industries also needed the capability to identify the opportunity, seeking the market, and develop networking. This knowledge can also be included in software education, to supplies the graduates if they want to become entrepreneurs. [P10]*

In the end, the construction processes of the competency model are driven by a varied set of motives that are not always clearly specified. The models are rarely limited to a specific purpose; instead, they mainly offer wide-ranging use across different beneficiaries.

Generally, competency models provide information on the competency requirements and offer guidance for improvement. In practice, competency models benefit jobseekers, students, graduates, practitioners, organizations and their HR management, academia, and communities in their basic functions, as described next.

Competency models provide information and guidance for competencies and levels of expertise required within their application domain. Based on primary studies, information can be valuable for new and existing practitioners, graduates, jobseekers, students, and anyone willing to improve their own skills. The competency model can also increase awareness of trends, industrial demands, and qualifications, and reduce ambiguity. Jobseekers and candidates pursuing a career can understand and develop the required competencies. Moreover, individuals can 'evaluate their own competencies to define a plan of action to develop their potential and correct their deficiencies' [P3]. Knowledge of the requirements can also help practitioners to preserve their jobs, change to another position in the same organization, get a promotion, or change to another organization.

Competency models benefit organizations and their HR management in many ways. Organizations can 'design the profile for each role' [P3] and assess role performance or competencies of their employees 'to determine whether people — have the suitable competences to work efficiently' [P5]. The models can also assist employers in identifying the 'spectrum of skills of local teams and compare these with what is currently in demand in the industry' [P20]. Organizations can identify training needs and organize training for their personnel, develop and adjust their training plans [P3], and 'prepare and educate [practitioners] for their roles' [P8]. On the other hand, knowledge of the necessary competencies can help employers offer financial incentives such as 'give rewards and bonuses for the level of proficiency the [practitioner] reaches' [P8]. Specifically, the model can be used as a 'tool for changing the organizational culture' [P8].

Competency models can help organizations' HR management in 'identifying personnel with precise capabilities for varying needs' [P14]

Table 5
International Competencies in Competency Models.

Content	N	Primary Studies
International	4	P6, P9, P20, P25

or 'improving — human capital' in general [P25]. HR management can benefit from competency models when assigning practitioners to new roles and teams, assigning teams to projects, and hiring new personnel. The organization can 'assess the competencies needed for a particular type of software or project and fill the — roles accordingly' [P22]. Moreover, knowledge of competency requirements can be used in the recruitment and hiring process to define recruiting profiles for job advertisements. Then, the organization can identify the best candidates based on the role profiles and competency assessment. Moreover, the organization can 'assess applicants' CVs and select the most appropriate profiles' [P5].

Based on the competency models, educational institutions can update their programs, incorporate competencies into their courses, and focus on industry-relevant topics. For example, academia can 'identify and consider for their curricula the competencies expected by the software industry' [P22] and then, 'develop specific courses and subjects specifically addressed to ensure that software engineers have the most appropriate competences to work' [P5]. The competency model can also be used to create a measurement instrument to evaluate competencies of students [P7] or teach in a 'goal- and competency-oriented approach' [P9].

In the end, competency models also assist the community. Competencies can be used to develop training and field-specific certifications. For example, 'the [Agile Project Management] movement can develop these competencies into a more comprehensive career and certification frameworks' [P21].

4.3. Communication, collaboration, intercultural, and language competencies

Regarding the content of the competency models, internationality is explicitly addressed in only 4 competency models. The studies that embedded international aspects into the models are presented in Table 5.

Only a few (4) competency models include explicit competency requirements for internationality. First, the model in the Open-Source application domain [P6] defines the 'International Community' category, including several social competencies: intercultural competencies, English language skills, and dealing with different styles of communication. Second, another competency model includes communicative competencies as follows:

> *'Software engineers need to be capable of accepting and understanding foreign views of the world and of reacting accordingly. They need to be willing to engage in foreign views of the world and they need to be capable of handling foreign views of the world appropriately'. [P9]*

Awareness of different views is also visible in a model for testing domain [P20] that extracted workplace diversity skills – work with diversity, global citizenship, and cultural awareness – from job ads with a low percentage. The fourth model for Scrum competencies in the global SE context [P25] regards as follows:

> *Communication: Able to manage synchronous and asynchronous communication in a global context with multidisciplinary teams (Scrum master, product owner)*
>
> *Cultural understanding: Able to understand the influence and implications of cultural differences (Scrum master)*
>
> *Coordination: Able to carry out new activities to manage clients and a development team geographically distributed (product owner) [P25]*

Table 6
Competencies in Primary Studies.

Competency	N	Primary Studies
Communication	29	P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29
Collaboration / teamwork	29	P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29
Intercultural	9	P3, P6, P9, P13, P14, P20, P25, P26, P29
English	4	P5, P6, P12, P18
Native language	1	P12
Language Proficiency	2	P2, P26

Table 7
Forms and expectations for communication.

fundamentals	**references**
listening	[P1, P11, P14, P19, P20, P22, P28]
observing	[P8, P11]
reading	[P7, P19, P20]
speaking	[P19, P20]
writing	[P7, P9, P19, P20, P26]
expectations	**references**
active	[P6]
clarity	[P11, P26]
conviction	[P11]
verbal fluency	[P11]
willingness	[P9]

These competencies refer directly to the global context and geographically distributed multidisciplinary teams. In fact, these Scrum-related competencies were collected from international participants as the sole study of these 4. Eventually, these 4 models reflect internationality explicitly through communication, interaction, and team, cultural, and language aspects, as well as global context and international community. However, the low number of occurrences indicates that internationality is not a predominant characteristic in the content of the competency model. Yet, internationality can be considered by actual communication, collaboration, intercultural, and language competencies whose presence in the competency models is presented in Table 6.

Communication and collaboration are embedded in all the competency models, highlighting the fundamental importance across various application domains. By contrast, most models lack intercultural and language competencies; Intercultural and language competencies are even depreciated. Each of these competency areas is analyzed separately in the following sub-sections.

4.3.1. Communication competencies

The importance of communication competency is evident since all the competency models (29) include communication in one form or another. Of the models, 9 [P10, P12, P13, P15, P17, P18, P24, P25, P27] address communication only by a single or high-level concept without specifying content in detail such as 'communicate orally and in writing in different settings' [P13] or 'effective communication' [P21]. Based on these single or high-level concepts, practitioners are expected to communicate effectively, orally and in writing in different settings and with technical solutions, give presentations, and maintain interpersonal relationships. However, the scrutinization of the other models consisting of multiple references to communication reveals the extensiveness of the competency needs, as presented in Table 7 and Table 8.

The competency models present expectations for fundamental, partly language-related, competencies such as speaking and writing but also address an ability to express oneself as well as an appropriate attitude. More detailed components are presented in Table 8.

Regarding the basics of communication, a communicator needs to

Table 8
Components of Communication Competency.

fundamentals	references
asking for help and questions	[P11, P14, P22, P26]
different styles of communication	[P6]
explaining concepts and opinions	[P4, P11, P16]
expressing opinions	[P11, P22]
generating ideas	[P14]
influencing others	[P20]
mediation	[P16, P19, P20]
moderation	[P11]
persuasion	[P8, P11]
presenting ideas and issues	[P1, P7, P9, P22]
providing and receiving feedback and critiques	[P6, P7, P9, P16, P26, P28]
reflection	[P23]
targeting communication at specific audiences, internal and external	[P4, P6, P9, P16, P22, P26]
verbal reasoning	[P1]
forms of oral communication	**references**
conversations	[P4]
discussions	[P7, P9]
interviews	[P11, P29]
meetings	[P11, P22, P29]
negotiations	[P1, P2, P8, P11, P16, P19, P20, P21]
presentations	[P6, P12, P19, P20, P29]
forms of written communication	**references**
documentation	[P1, P3, P6, P11, P22, P26, P29]
emailing	[P6]
meeting records	[P11]
structured writing	[P4]
reporting	[P11, P26, P29]
social interaction	**references**
behaving with social and ethical norms and rules	[P6, P9]
conflict resolution	[P1, P3, P5, P9, P11, P16, P19, P20, P21, P26]
customer service	[P2]
diplomacy	[P8, P20]
emotion management	[P1]
handling criticism	[P9]
human encounters	[P22]
interaction	[P3]
interpersonal relationships	[P1, P3, P5, P8, P10, P11, P14, P22, P23]
interpersonal sensitivity	[P1, P3]
openness	[P22]
politeness	[P3]
show empathy and kindness	[P1, P3, P8, P9, P11, P20, P26, P28]
sociability	[P1, P6, P7, P20, P22]
understand aspects of other people	[P11]

know different communication styles and be able to ask for help, explain concepts, express opinions, generate and present ideas, influence others, present ideas and issues, reflect, and master verbal reasoning. Many of these fundamentals are applied in both oral and written communication or, from another perspective, in different social situations. Communicative situations may also require mediation, moderation, and persuasion, as well as providing and receiving feedback and critiques. Orally, these are manifested in many forms, such as meetings and negotiations, and in writing, such as documentation and emailing.

As communication is social interaction, it is grounded in human encounters and interpersonal relations that require sociability, interpersonal sensitivity, empathy and kindness, openness, and politeness. Social actors, according to the models, are expected to behave according to the social and ethical norms and rules that may be different in diverse groups. Generally, a communicator needs to know different forms and norms for internal and external communication. Communication is always targeted at a specific audience and requires communication at an appropriate level. The greatest challenges in social encounters may concern disagreements and disputes. Then, a social actor is required conflict resolution competencies, diplomacy, emotion management, and abilities to provide and receive feedback and criticism, which are,

Table 9
Components of Collaboration Competency.

characteristics	references
collaborative	[P29]
team-oriented	[P12, P14, P23]
is a team player	[P17]
occupies a team member role	[P15]
accept responsibilities	[P9]
balance the commitments	[P1]
follow an agenda, processes, and rules	[P1, P26]
agile aspects	**references**
agile development	[P15]
agile framework	[P18, P21]
agile methods	[P21, P22]
agile principles	[P21]
with stakeholders	[P4, P8, P25, P26]
with customers	[P4, P25]
with other developers	[P4]
understand customer needs	[P22, P23]
customer focus	[P12, P21]
customer orientation	[P14, P23]
stakeholder management	[P11, P21]
together	**references**
available	[P26]
balance goals with own priorities	[P1]
celebrate team success	[P16]
concern for people	[P16, P28]
driven by a desire to contribute	[P23]
lack of ego	[P23]
open to other's ideas	[P7]
share information and knowledge	[P11, P16, P17, P22, P23]
share success	[P3]
show trust	[P16]
social influence	[P27]
support decisions	[P16]
works for a shared goal	[P26]
willingness to belong to the whole	[P6]
willingness to work according to agreements	[P5, P7]
actions	**references**
coach	[P16, P19, P20, P25]
consult	[P4]
guide	[P16, P26]
help	[P14, P16, P23, P26]
learn from others	[P22]
mentor	[P17, P25, P26]
seek help	[P14, P23, P27]
support	[P1, P16, P28]
teach	[P22, P25, P26]
leadership and coordination	**references**
driver	[P14, P23, P26]
leadership	[P1, P4, P5, P11, P15, P21, P23, P25, P27, P28]
project / team leader	[P26]
team organizer	[P22]
coordinate activities	[P4, P11, P12, P25, P26]
delegate	[P26]
drive alignment	[P16]
encourage to try new things	[P16]
ensure roles and responsibilities	[P4]
facilitate independent decision making	[P16]
facilitate team working	[P25]
give responsibility	[P16]
provide direction	[P10]
share leadership	[P1]
support experimentation	[P16]
independence	**references**
autonomy / independence	[P2, P11, P22]
initiative	[P11, P14, P15, P22, P23, P26]
make decisions	[P1]
proactive	[P1, P2, P11, P14, P17, P23]
proactive with management	[P14, P23]
self-confidence	[P11]
self-directedness	[P9]
self-organization	[P12]
self-management	[P18, P27]
set goals	[P16]

(*continued on next page*)

Table 9 (*continued*)

characteristics	references
agreements and disagreements	**references**
allow different opinions	[P1]
compromise	[P22]
fulfill agreement	[P7]
gain agreement	[P4]
make agreement	[P7]
listen to others	[P1, P22]
promote fairness	[P4, P16]
understand dynamics of debates	[P1]
willingness to confront others	[P14, P23]
spirit	**references**
energize team	[P16]
peace-making	[P25]
maintain a positive working environment	[P16]

indeed, significant also in daily encounters. In professional situations, communication can be part of bug reporting, code review, writing situation reports, and documentation.

Regarding the expected level of communication competency, communication belonged to the set of three most important soft competencies in 8 studies [P12, P18, P19, P20, P24, P26, P27, P29]. From another perspective, several job roles require the highest expertise level. For example, 2 studies [P1, P2] assigned communication to the highest rate for the roles of project manager, analyst, quality engineer, and documenter. Moreover, the highest rates were given in singular studies for various testing practitioners [P1, P5], designers and specialists, change manager, architect [P2], and product owner [P18].

Regarding the sub-components of communication, importance varies from high to low. For instance, negotiation was rated as the highest possible competency level for about half of the roles, such as project manager, analyst, as well as several engineering and specialist positions [P1, P2]. On the other extreme, negotiation was determined as unnecessary for a documenter and tester [P2]. Moreover, 3 other studies [P19, P20, P21] report on the lower importance for negotiating. Similar variation is also visible in interpersonal relations and sociability, varying from low level [P20] to the highest possible rates [P1, P5]. An exceptional interpretation of the importance of communication was made by [P22], who took several competencies for granted, such as social skills, listening ears, asking questions, and communicating ideas. In contrast, a communicator was expected to have communication, human, interpersonal, and meeting skills, openness, voicing own opinions, writing documentation, contacts with clients, as well as team organization and communication skills. Unexpected delight is brought by communication to the outside world and sociability [P22].

In sum, professional communication is a multifaceted, extensive competency area that facilitates the flow of information and professional relationships by fundamental communication activities and social interaction through oral and written communication. These findings demonstrate the diversity of communication in SE. Communication plays a vital role in job performance even though not all the sub-components require the highest possible competency level.

Table 10
Components of Intercultural Competencies.

component	references
cultural awareness	[P20]
cultural understanding	[P25]
dealing with different styles of communication	[P6]
global citizenship	[P20]
respect, appreciate the values, beliefs, cultures, and histories of others	[P3]
accept and understand foreign views of the world	[P9]
value diversity	[P14]
workplace diversity	[P20, P26]
work in groups in different settings	[P13]

4.3.2. Collaboration competencies

The importance of collaboration competency is evident since all the competency models include collaboration and / or teamwork in addition to that the models specified collaboration by multifaceted sub-components. In fact, only 4 models [P3, P13, P24, P29] address collaboration or teamwork only by a single or high-level concept without specifying content in detail such as 'work in team' [P3]. Based on these high-level concepts, an SE practitioner is expected to work in teams and collaborate in different settings. More detailed components of collaboration and teamwork are presented in Table 9.

Based on the competency models, the software industry needs collaborative, team-oriented individuals who commit to a role in a team, accept responsibilities, and follow procedures. Moreover, individuals are required knowledge of the agile paradigm since software construction is often guided by agile principles and customer collaboration with a focus on the customer needs.

In teams and groups, individuals are expected to be available, work together for shared goals, share information and knowledge, and contribute to shared success. Individuals need to be open to others' ideas, show trust, and demonstrate a willingness to belong to the group. Particularly, individuals need to lack ego. Indeed, software practitioners need to coach, consult, guide, help, mentor, support, and teach each other.

Despite the strong emphasis on collaboration, individuals are also required leadership and independence. As shown in the models, software practitioners need leadership competencies. While teams and projects have leaders who coordinate activities, delegate, facilitate, direct, and support, individual team players are also required leadership competencies. Individual collaborators also need abilities in autonomy, initiative, proactivity, and self-organization. Collaborators must be able to make decisions independently and manage work.

The competency models also highlight agreements and disagreements. Individuals must understand the dynamics of debates to identify common ground and build consensus. Individuals confront each other, to advance team objectives to reach an agreement. Therefore, an individual needs to be able to listen, compromise, and allow different opinions. Effective collaboration requires promoting fairness. The work communities also appreciate peacemakers and other individuals who maintain a positive working environment.

The importance of collaboration and teamwork appears in studies because collaboration, including teamwork aspects, belonged to the set of three most important soft competencies in 7 studies [P17, P18, P19, P20, P24, P27, P29]. On the other hand, cooperation, teaching and sharing knowledge, and compromising can even represent competencies that can be taken for granted [P22].

Moreover, the significance of collaboration and teamwork is demonstrated by the level requirements. The highest-level requirement for teamwork or collaboration is suggested for almost all the roles [P2, P5, P18] such as managerial, specialist, and designer roles [P2], Scrum master and team members [P18], analyst, programmer, documenter, and tester [P2]. Also, independence and proactivity are required with the highest rates from several managers, designers, and specialists but also from an analyst and programmer [P2]. The highest leadership rates are determined for various managerial positions [P1, P5].

In sum, collaboration and teamwork represent a multifaceted, extensive competency area that intersects often with communication. The identified components demonstrate the diversity of collaboration and teamwork.

4.3.3. Intercultural competencies

Intercultural competencies were included in 9 of 29 competency models. The representations of intercultural competencies or ethical and intercultural perspectives address the components presented in Table 10.

The components of intercultural competency rely on 9 competency models. These competency models convey a need for cultural awareness

Table 11
Components of Language Proficiency.

component	references
English, local native language, other languages	[P12]
Second language	[P18]
English	[P5, P6]
localization	[P26]
translation	[P26]

and understanding as well as mastery of different communication styles. Individuals are also expected to be able to work in different settings and show respect and appreciation of the values, beliefs, cultures, and histories of others.

In a paper [P26], cultural aspects were linked to collaboration competency that facilitates groups of people with different cultural backgrounds, with different skill bases and in various time zones to work together. Similarly, a study [P13] tied intercultural competencies to collaboration; in fact, the paper simplified original statements of the competency hierarchy – working in an international group and working with people that are very different from you – to the form of 'work in groups in different settings.' Moreover, a paper [P1], which, in fact, omitted cultural competency from the final model, associated cultural competency in text with interpersonal relations presenting that individuals can respect and appreciate the values, beliefs, cultures, and histories of others to create an environment in which they feel welcome and included, and in which they can grow. Despite ignorance, this paper [P1] modeled interpersonal relations by communication, adaptability, aptitude to relate, sociability, and interpersonal sensibility.

Regarding data collection of studies that addressed intercultural competency, 2 studies collected data from students – either from 4th-year [P13] or master [P1] students. In addition, intercultural perspectives were considered in the sole curriculum-based study that investigated the learning objectives of the project-based undergraduate SE courses [P29] and SWEBOS [P9]. In fact, intercultural competency was mentioned in all the student or curriculum-related studies. Secondly, intercultural competency was covered in the studies conducted in the domains of open-source software (2) [P6, P26] and global development (1) [P25]. Other rare occurrences of cultural aspects were covered in studies referring to agile development [P14, P25], job ads in the US [P20], and software process improvement [P3].

In sum, intercultural competency is not recognized as a core component of the competency models, as exhibited in the low number of identified components. Cultural instances arise mainly from educational research contexts and from domains with inherent international dimensions.

4.3.4. Language competencies

Language proficiency was included in only 6 competency models: 4 models mentioned the English language, 1 model both English and native language whereas 1 referred to language proficiency in general. The rare inclusions of language components of the competency models are presented in Table 11.

Generally, competency models refer to a foreign or second language, English, native language, or other languages. One study [P12], which included both English and the native language in the model, contained also other foreign languages; in fact, the most-in-demand soft skill in that study was proficiency in the native language, followed by communication, analytical skills, and proficiency in English. On the other hand, another model [P2], which handled languages under general 'language proficiency' competency, suggested the highest possible level requirement for more than half of the job roles such as project leader, various designers and specialists, architect, analyst, and documenter. By contrast, a programmer [P2], tester [P2, P5], and testing manager [P5] positions are not expected to possess the highest level of proficiency. In addition, one model [P18] regarded a second language (English) as one of the least significant soft competencies; notwithstanding, it was included in the model.

Additionally, the English language was present in 2 studies even though it was ignored from the final competency model. According to a study conducted in two countries [P11], foreign languages had a relatively noticeable importance in one country but lower in the other. In another study [P13], students' observations covered the need to communicate, argue, discuss, and write in English but the final model contains only 'communicate orally and in writing in different settings.'

Overall, language proficiency is not highlighted. In fact, the aspects of languages were covered in the same 2 open-source software and 1 student-based study that included also intercultural competency, suggesting that the presence of one can imply the other. Otherwise, languages were covered in a miscellaneous set of studies regarding 2 job ad studies, software process improvement, testing, and agile development domains. In the end, language proficiency is not regarded as a core component of the competency model.

4.4. Elements of competency model construction

The construction of the competency model consists of many phases and demands several choices such as application domain and job roles covered in the model that were described under RQ1. In addition, model construction requires many other decisions on the conceptual basis and competency categories, level specifications, granulation, research approach and methods, and visual appearance. These aspects are covered in this section. Illustrative examples are chosen from the areas of communication, intercultural, and languages.

4.4.1. Conceptual basis

The competency models are based on different competency-related concepts. Most of the studies are conceptually grounded in 'competency' (17), 'skill' (8), or 'competence' (6), either independently or in conjunction with another concept. Out of 29, 22 studies are grounded in a single concept, most of them (12) in 'competency,' whereas the others relied singly on 'competence,' 'skill,' 'attribute,' or 'characteristic.' Seven studies incorporated two different concepts. For example, 2 studies utilized both 'competency' and 'competence,' 2 'competency' and 'skill,' and 1 'attribute' and 'capability.'

Conceptually, some authors defined their conceptual basis rigorously whereas in the other extreme, some took the main concepts for granted. Regarding the studies that entail a rigorous conceptual basis, 'competency' was, for example, regarded as a component-based concept, as a 'set of specific knowledges, experiences, skills, training, attitudes, and behaviors' [P3] or as 'a combination of skills, knowledge, and abilities' [P24]. Similarly, another study [P1] grounded competency on components 'knowledge, abilities, and behaviors' but integrated the concept with 'functional and behavioral approaches' in a holistic manner. Studies also connected competencies to effective performance at work, professional context [P13], and job requirements [P4].

Neither the concept of 'skill' was defined unambiguously. Skill was regarded as 'a set of individual capabilities that enable efficient and effective performance in teams working on SE projects using agile frameworks' involving both soft and technical skills [P18] whereas another [P26] considered skills as 'anything that an individual can actively work to improve on' encompassing both formal skills and personal attributes of contributors.

Moreover, there were studies that ignored the detailed conceptual difference, referring to the use of concepts as synonyms. One [P23] defined 'competence' but searched 'competencies,' and another [P11] identified competences but relied on the variety of competency, competence, knowledge, skills, attitude, ability, and attribute.

Rather often the conceptual basis relies on the theoretical background where several concepts are covered but not defined. Moreover, some studies just use concepts without examining them theoretically. Ultimately, there is no consensus on the conceptual basis even though

'competency' seems most prevalent. Some studies treated these competency-related concepts as distinct, some side by side, and some as if as synonyms.

Moreover, the conceptual basis is related to the choice of the viewpoint type such as relevance and importance. Of 29 primary studies, 17 specified the type of competency that they were seeking albeit counts were rather low and varied. For example, the studies explored 'essential competencies' [P23], 'relevant skills [P26], 'important attributes' [P16], and 'skills required by market' [P11]. In sum, the studies sought essential (3), most important (3), critical (2), relevant (2), 'required by market' (2), 'required' (2), important, necessary, key, requisite, or useful competencies. Different concepts combined with varying viewpoints bring attention to different facets of competencies, despite not always seeming particularly intentional.

4.4.2. Competency categories

Competency models categorize competencies in different ways employing diverse technical, soft, and domain-specific category names or dimensions. Reflecting also the applied conceptual basis, 17 of the 29 models relied on a basic division between technical and soft with variations and 7 models on application domain visibility. Generally, models exhibit structural diversity with varying emphasis. For example, 7 models employed additional subcategory structures under the main categories. Moreover, one model integrated two crossing dimensions [P16] while another treated competencies without classifications [P18].

Regarding the competency categorizations relying on the division between technical and soft competencies, the simplest solutions classified competencies dichotomously into technical and either soft, general, generic, or behavioral competencies. In some models, the simplest categories such as 'generic and technical' [P2] were extended by a few categories resulting, for example, in 'technical, social, and personal' [P6], or 'technical, soft, and testing' [P20] – the latter also exemplifying a combination of technical, soft, and domain-specific categories. The category labels convey conceptual variability as they also involved 'dispositions,' 'knowledge,' 'skills,' 'attitudes,' and 'personality traits,' as well as 'professional,' 'project-specific,' 'interpersonal,' 'social,' 'innovative,' and 'organizational' category labels.

In the context of application domain visibility, the simplest solutions classified competencies dichotomously into the opposing – domain-specific and general – categories such as 'RE / non-RE' [P12]. More typically, domain-specific classifications introduced multiple categories as seen in the following example:

> *understanding and applying the Scrum framework, developing people and teams, managing products with agility, developing & delivering products professionally, evolving the agile organization [P25]*

This comma-separated list of categories illustrates the embedding of competencies within the Scrum-related application domain.

All the competency categorization solutions were not unidimensional; one model was based on crossing dimensions while describing a great SE manager [P16]. The first dimension was based on manager functions such as cultivates, motivates, and mediates whereas the second dimension crossed the first dimension by the levels of interaction: 'with individual' and 'with team / organization.' More typically, the perspective was extended by additional subcategories, as seen in the following example:

> *technical: technical knowledge, use of technology.*
>
> *social: interpersonal relations, cooperation and work in team, handling and solving conflicts.*
>
> *personal: development in the job environment, personal development, rights and limits. [P1]*

This illustrates how the main – technical, social, and personal – categories were extended by several subcategories.

Overall, competency models exhibit structural diversity when classifying competencies. Most models represent a straightforward division between technical and soft competencies with variations, even though many category labels also reflect the application domain. The diversity also resulted from variations in the conceptual basis as well as the inclusion of additional sub-categories and dimensions.

4.4.3. Levels of expertise

Half (15 of 29) of the competency models [P1, P2, P5, P12, P15, P17, P18, P19, P20, P21, P22, P24, P26, P27, P29] include the level of expertise in order to indicate the degree of expected mastery, how strong a competency is expected, or how important competency is in relation to other competencies. Most often the utilized expertise levels are based on an ordinal scale variable, either with a numeric value or an adjective, but the level can also be based on other scales, a dichotomous word pair or even statistical descriptives and percentages.

A numerical scale – such as '0–3′ or '1–5' – was applied in 3 models [P1, P2, P18] in conjunction with adjectives, as illustrated in the following example.

> *3-level scale from 0 to 2 with 0 = unnecessary, 1 = fairly necessary, and 2 = very necessary*
>
> *Competency: Language Proficiency*
>
> *Level 2: project leader, designer*
>
> *Level 1.5: technical specialist*
>
> *Level 1: programmer [P2]*

Numerical scales were used to specify the expected competency levels for various job roles. As illustrated in the example, language proficiency expectations for a project leader and designer are defined as '2′, i.e., 'very necessary.' On the other hand, numbers are not always necessary; mere adjectives can also serve as indicators of the expected competency level as follows:

> *Case: Agile Project Manager Competencies*
>
> *High demand: teamwork, effective communication*
>
> *Moderate demand: leadership*
>
> *Least demand: self-organization, conflict resolution, agile mindset [P21]*

This example illustrates the use of 'high, moderate, and least demand' scales for agile project manager competencies generally. Another paper [P5] utilized adjectives – low, medium, high, and very high – to define expected competency levels for several job roles.

Competencies were also classified using specific, label-based categories [P22, P24]: while one model [P24] classified competencies into 'must have' and 'game changer' competencies, the other [P22] relied on the scale of 'basic,' 'performance,' and 'delighter.' Here, competencies are classified as 'basic,' when considered pre-requisite, necessary, expected, or taken for granted. 'Performance' refers to competencies that are expected and when delivered well cause more satisfaction whereas 'delighter' refers to unexpected competencies that increase delight when available [P22].

Additionally, the importance of competency can be indicated by statistical descriptives [P17, P24, P27] or percentages [P12, P15, P19, P20, P29]. For example, mean values can be used to rank competencies according to their importance based on the explicit or implicit numeric analysis. The following example illustrates this:

> *Top 3 'must have' soft skills in the new normal: communication skills, result-oriented, and collaboration [bar chart], weighted averages [text]: communication skills 3.78, results-oriented 2.00, and collaborations skills 1.67 [P24]*

This illustrates an explicit quantitative measurement where classification of competencies was based on numeric, threshold values. On the other hand, a numeric measurement can function as an indicator of

importance even without the threshold values. In the following examples, the importance of competency is explained by percentages and descriptives:

Occurrence of professional and foundational knowledge elements [in learning objectives]: collaboration and teamwork 91 %, oral communication and presentation 65 %, and ethical and intercultural perspectives 24 % [P29]

Distribution of sought soft skills [% of job ads]: 65 % native language skills, 56 % communication skills, and 41 % English language [P12]

The most important skills: analytical / critical / creative thinking 4.756, teamwork 4.717, and oral / written communication skills 4.685 [based on a scale from 0 = not important to 5 = very important] [P27]

These examples illustrate how the interpretation of the importance can be made of numeric values; the higher value, the more important competency. The frequency of occurrences can be used to rank competencies [P21]. The comparison between values and the use of the relative magnitude of the value enables the evaluation of the importance. Moreover, a scale can be built on pictograms, as seen in the following example.

Analysis of survey mentions: Communication 𝍸𝍸𝍸𝍸𝍸, collaboration 𝍸𝍸𝍸𝍸, and conflict resolution 𝍸, where 𝍸 = 1- 10, 𝍸𝍸= 11–20, 𝍸𝍸𝍸=21–50, 𝍸𝍸𝍸𝍸= 51–100, and 𝍸𝍸𝍸𝍸𝍸= 100+ survey mentions [P26]

This example clearly illustrates how the importance of competency – illustrated by pictograms– is based on survey responses.

All competency models do not specify the expected level or importance of the competency – albeit even the inclusion of a competency in the model can indicate importance or necessity. The degree of expected mastery or importance of competency can be conveyed with numeric, adjective, or other scales as well as statistical figures and percentages. Through classifications and numerical indicators, competencies can be stratified to distinguish between those of minimal importance and those that hold greater significance.

4.4.4. Granularity and definitions

Competency models exhibit rather different granularity levels. Sometimes a particular competency was regarded as one extensive competency area whereas some other models chopped the competency into separate related sub-competencies. The following examples illustrate different granularity levels. Each item in the following comma-separated lists refers to one independent competency included in the model.

Effective communication [P18]

Communication, active listening, know how to give feedback [P28]

Communicate to the outside world, communication skills, interpersonal skills, open and communicating, voice your own opinions, meeting skills, listening ears, ask questions, team organization and communication skills, communicate ideas, writing documentation [P22]

In the first example, communication is covered by a sole competency in the model whereas the second illustrates the chopping of competency into three individual elements. At the other extreme, the last example shows the high granularity, chopping into separate, numerous competencies.

The studies also differ in how they define or describe the competencies included in the model. Here, 17 competency models were attached to descriptions or definitions of the competencies whereas the rest of the studies rely on the shared understanding of the nature of the competency. Most often, competency descriptions were included in the tabular competency model itself (6) [P9, P11, P19, P20, P23, P26], provided in the text (5) [P3, P8, P17, P18, P28], or in another table (5) [P4, P16, P21, P25, P29]. One paper sought topics by keywords [P15] conveying the meaning of competencies. The following examples illustrate different competency descriptions and definitions.

"Communication. Clearly communicates with others in written and oral forms" [P26]

"Communication: Leaders need to be understood by the team, transmitting information clearly or being transparent whenever possible." [P28]

"Communication: Able to carry out new activities and bridge communication between consumers and the development team, onshore and offshore, illustrating challenges by providing support, direction, and clear structure to the development team" [P25]

The first example describes a competency in a theoretical context whereas the others tie the competency to the job roles, duties, or communicative functions. In addition to full sentences, a competency can be defined by a list of sub-competencies, as shown below:

Communication: Listening communication, presentation skills, reading communication, speaking communication, and writing communication [P19]

This example illustrates a simple listing of the sub-components whereas the following example demonstrates rigorous specification of competency:

Effective communication: Ability to listen and understand the other, transmitting the information required by the agile team in a clear and timely manner. The individual must use and maintain open communication channels to fulfill the project objectives.

Level 0: Listens carefully to the members of the team. Communicates the ideas clearly and understandably. Asks the right questions to get the information needed to get things done. Maintains adequate communication with the members of the work team.

[Level 1 and 2 descriptions left out from this extract.]

Level 3: Listens and understands others, keeping communication channels open. Clearly and timely transmits the information required by others, facilitating the achievement of the team's objectives. Structures organizational communication channels that allow establishing relationships with all team members. Develops formal and informal contact networks that allows to create a positive environment for intercommunication. [P18]

This exemplifies how competency is, at first, defined rigorously and then, described separately for each expertise level, minimizing interpretation and misunderstandings.

In sum, competencies, their content and coverage, can be treated in different ways in competency models. The level of detail varies. Competency areas are presented varyingly as one more extensive, high-level concept and numerous, chopped sub-competencies. Regardless, most studies describe or define their competencies by descriptions, definitions, or lists of components presented either in a theoretical or application domain context through job roles, duties, or activities. Most rigorously, competencies were defined separately for each expertise level. Some studies disregard descriptions and definitions and hence rely on a shared understanding of the nature of competency.

4.4.5. Applied research methods

The primary studies applied both qualitative and quantitative research methods as well as a variety of different strategies, and data collection and analysis methods. The methods that were used to collect data for competency models are represented by primary studies in Appendix D.

The qualitative method was more widely utilized; almost all the studies (28) employed qualitative methods, either independently (10) or in conjunction with a quantitative method as a mixed method (18). In

fact, only 1 study relied on the quantitative method.

Regarding the utilization of different data collection methods, 13 primary studies applied a sole data collection method whereas at the other extreme, 2 studies [P3, P25] employed more than three methods. The most often employed data collection method was an interview (16) followed by a literature review (10). Other frequently used methods comprise surveys, questionnaires, and job ads from 6 to 7 occurrences. The primary studies also employed systematic literature review and observation.

Regarding data collection methods, the primary studies employed interviews, surveys, questionnaires, and observation. Methodological variation is demonstrated in the following examples:

1) interview of 25 IT leaders [P28]

1) 37 semi-structured interviews 2) Survey with 563 responses [P16]

3-round Delphi: 1) brainstorming questionnaire for experts and skills gathered from literature 2) questionnaire to narrow down the skills 3) ranking questionnaires 4) follow-up interviews [P17]

These examples illustrate the utilization of one, the interview method independently or in conjunction with other methods, illustrating a common methodological variation in the primary studies. The interview was employed as a sole method in 4 primary studies but was more frequently (6) combined with literature reviews. The interview was also employed with survey, questionnaire, focus group, observation, documents, and informal conversations. Also, the role of surveys, questionnaires, and observations varied similarly.

The second most often utilized method was a literature review. This secondary data collection method was not used as a single method, with no regard to 2 SLRs. The literature was utilized in 10 studies to support other data collection methods as illustrated in the following examples:

1) Create a competency framework from literature 2) Analysis of job ads using deductive content analysis [P21]

1) Literature review, curriculum analysis → theoretically derived competence model 2) Interviews using the critical incident technique, qualitative content analysis → empirically refined competence model [P7]

1) literature study → a list of competencies and in-depth interviews → a strengthened list of competencies 2) content analysis 3) Validation using focus group [P25]

The literature review was typically used to collect competencies or create a tentative framework; The framework was refined and validated in later steps. Moreover, the primary studies applied different research strategies, as demonstrated in the following examples:

1) Ethnographic technique (field observations, interviews, and questionnaires) during 7 years with 9 groups of CS master students working with project with real clients for a SE class 2) grounded theory and functional analysis [P1]

1) literature review 2) 3 case studies in 3 small SD organizations within 2 years. Ethnography (observation, field notes, interviews) within 5 months. Application of action research (observation, interview, questionnaire) 3) creation of framework 4) evaluation with 10 interviews and 2 empirical tests [P3]

These examples illustrate methodological diversity under different research strategies. Altogether, the primary studies applied Grounded Theory (4), case study (3), Delphi (3), ethnography (2), and action research (1) strategies. Furthermore, the primary studies employed a job ad method as seen in the following example:

1) 1000 online job ads collected 2) data extraction and qualitative coding 3) free-text analysis employing natural language processing (NLP) [P20]

There were 5 primary studies that collected data from job ads. These job ads were analyzed by various qualitative and quantitative analysis methods, as well as by natural language processing.

The primary studies employed different qualitative and quantitative analysis methods. The most frequently used analysis method is descriptive statistics (16), used in all the studies that applied the quantitative method. Descriptive statistics was utilized in the form of counts, percentages, tables, and charts. Instead, inferential statistics was used more rarely (4) in terms of statistical significance, statistical inferences, and correlations. Correspondingly, studies employing the qualitative method utilized different analysis methods of which content analysis (10) was the most frequently used. Moreover, there were studies (11) that ignored a more rigorous specification of the qualitative analysis method, referring solely to 'qualitative analysis.' The studies utilized also thematic (4) and functional analysis (1).

In all, both qualitative and quantitative methods were applied in the construction of the competency model. The primary studies represent methodological diversity with various mono- and multi-method approaches. Most typically, data for the competency model were collected by interviews, surveys, and questionnaires, and supported by literature. Methodological diversity appears also in applied analysis methods and research strategies.

4.4.6. Data sources

This section describes from whom and from what types of literature sources competencies for the identified competency models were collected. Data for competency models were derived from both empirical studies involving human participants and from a wide range of existing literature. Overall, 12 studies collected data only from people whereas 9 of the models based their competencies on existing literature. 8 studies applied both data sources.

The utilization of both empirical and literary data sources in competency identification is illustrated in the following example.

1) Competencies identified from journal articles, conference papers, and books, 2) Competencies were validated by 3 entrepreneurs → the proposed model [P10]

Here, the proposed competency model was based on comparison, leveraging both human participants and literature review. A more detailed analysis of these human and literary sources is provided in the subsequent paragraphs.

Regarding empirical studies with human participants, data were mostly collected from the software industry (17): from practitioners, teams, and software companies. Respondents or participants comprised various software practitioners representing diverse roles across different projects, academic backgrounds, and industrial sectors. Research subjects represent various engineers, developers, professionals, practitioners [P3, P4, P5, P6, P8, P9, P16, P18, P27], experts, seniors, experienced practitioners [P2, P3, P7, P17, P22, P24, P25, P27], as well as leaders and managers [P6, P8, P16, P22, P28]. In practice, data was collected from 'common' software engineers and practitioners having a specific role such as testers, requirement analysts, business analysts, entrepreneurs, and customer representatives. In addition to team and project leaders, data were collected from general, program, HR, and executive managers. Other participant groups including academics, students, mentors, contributors, entrepreneurs, and conference participants appeared more sporadically. Regarding academia, data were collected from educators [P7, P9], graduates [P27], and master [P1] and 4th-year [P13] students.

International participants were also represented. There are 5 primary studies who collected data across various geographic locations. Survey data for an Open-Source -related study [P26] was collected from contributors across Africa, the Americas, Asia, Europe, and Oceania, encompassing a wide range of ethnicities, including, for example, White, Asian, and Middle Eastern. Another survey [P27] collected responses from 13 countries across Europe, Asia, and North America. Moreover, 2 studies conducted interviews in 2 to 4 countries [P4, P25] and one study

Table 12
Representations of the competency models.

Appearance	Primary Studies
tabular	P1, P2, P5, P6, P7, P9, P10, P11, P13, P14, P15, P17, P18, P19, P20, P21, P23, P26, P29
graphic	P4, P16, P22, P25, P28,
statistical chart	P12, P24, P27
text	P3
graphic and tabular	P8

[P22] gathered data through a focus group discussion at international conferences. Furthermore, 4 primary studies [P5, P16, P24, P28] collected data from international or multinational companies.

The number of human participants varied by the applied methods. In surveys or questionnaires, respondent numbers ranged from 80 testers [P5] to 628 software practitioners [P27]. Similarly, the number of interviewees varied from 3 entrepreneurs [P10] to 64 requirement analysts [P4]. The ethnographic study was built on nine groups of master students [P1]. Moreover, one paper organized a focus group with 8 experts [P25] and another with conference participants [P22]. The Delphi studies involved 9 to 35 experts.

Regarding literature sources, competencies for competency models were derived from research literature, articles, books, websites, manuals, expert opinions, curricula, methodological and curricular guidelines, and job ads. Of the 17 primary studies who utilized existing literature, 4 relied on scientific literature [P3, P10, P17, P26] and 4 on job ads [P12, P15, P19, P20]. Generally, literature reviews were strongly based on scientific literature even though studies also utilized international guides and frameworks, and other written materials as illustrated in the following examples:

> *SWEBOK, SE2004, PMBOK, The White Book, Career Space, TMap, TMM, TMMi, ISTQB, The 11-step Testing Process [P5]*

> *Computing Curricula 2001, Model Curriculum for K-12 Computer Science, OECD, RUP [P7]*

> *Scrum.org [P25]*

These examples illustrate varying and broad employment of international curricular guidelines, general frameworks, bodies of knowledge, methodologies, and other guides. Only 2 studies [P5, P22] utilized the international curricular guidelines described in the Related Work section of this paper. Still, many primary studies referred to them in literature without utilizing them to gather competencies.

In numeric terms, the two SLR studies employed 16 [P14] or 60 [P23] primary studies. A study analyzed 31 syllabi [P29] and the number of online job ads varied between 101 and 2638. In fact, two primary studies collected job ads from two countries [P11, P21].

Overall, competencies were identified from both human participants and a wide range of existing literature – both independently and in combination. Human participants were mainly recruited from the software industry even though data were also collected from academia and other relevant contributors. However, international participants were rarely included. While the use of literature emphasizes scientific literature, competencies were also derived from other written materials including guidelines, frameworks, websites, curricula, and job ads.

4.4.7. Appearance

Competency models represent a variety of forms. The basic distribution of the main representations is shown in Table 12. These structural representations are exemplified in the graphic model library in Appendix E with references to Figs. E.1–E.13.

Tables and collections of tables (19) constitute the preferred method for organizing and displaying competencies even though the models are not limited to tables. The models also encompass graphic (5), statistical chart (3), and textual (1) representations reflecting diverse preferences

Table 13
Summary of the Elements in the Competency Model Construction.

Choices	Option	Examples
Fundamental		
Application domain	general	SE
	limited	Software testing, Blockchain
	**context: international, global*	
Job role(s) included		software engineer, analyst, project manager, architect, security specialist, product owner
Practical scenarios	knowledge about competencies, level of expertise, and industrial demands	beneficiaries: practitioners, graduates, students, jobseekers
	competency improvement	beneficiaries: organization, HR management
	job descriptions	beneficiaries: academia, teachers
	performance and competency assessment	beneficiaries: community
	organize training for personnel	
	assigning practitioners to new roles, teams to projects	
	recruitment	
	update curriculum and syllabus	
	develop teaching	
	certification frameworks	
Conceptual		
Conceptual basis		competency, competence, skill, attribute, characteristic, knowledge area
Type		essential, the most important, required by market, critical, necessary, key
Representation choices		
Categories	technical, soft (with variations)	social, generic, innovative, professional
	conceptual	knowledge, skills, attitudes
	application domain -specific	RE, non-RE, managing products with agility
	**context specific category*	international community
	one- or multi-level	
Level of expertise /Importance	ordinal scale: number, adjective	0–3; low, mediate, high
	dichotomous scale	'must-have,' other
	classification	pre-requisite, expected, supplementary
	statistical descriptive	count, percentage, mean
Granularity level	High-level concept	communication
	Division into sub-components	listening, presentation, asking for help, explaining
Definitions / Descriptions	place of the definition	in the model, text, another representation
	form	full sentence, list
	context: theoretical or practical	application domain -specific
	general or expertise level -based	
Appearance	tabular, one- or two-dimensional	mind map, basic shapes
	graphic	bar chart
	chart, statistical representations	
	textual, list	
Methodological		
Research method	mixed, qualitative, quantitative	
Research strategies		action research, case study, Delphi, ethnography, grounded theory
Data collection		interview, survey, questionnaire, observation, focus group
		literature, job ads, documents, SLR

(*continued on next page*)

Table 13 (*continued*)

Choices	Option	Examples
Subjects	software industry	companies, teams, practitioners
	community	mentors, contributors
	academia	educators, graduates, students
	**context: international*	international / multinational organizations across geographic locations
Individual Subjects	academic background	seniors, experts, 'ordinary' practitioners
	expertise level	
	job role in the project / at work	software engineer, tester, team leader, Blockchain engineer, entrepreneur
	** country*	
Written sources	literature	research literature, books, websites, manuals, guidelines, curricula, job ads
	**international sources*	international literature, general guidelines and frameworks
Analysis methods	quantitative	descriptive statistics, inferential statistics
	qualitative	qualitative analysis, content analysis, thematic analysis, functional analysis
		natural language processing

* international aspects.

in the level of detail.

The simplest forms of competency models are tabular, one-dimensional lists of competencies (Appendix E, Fig. E.1) and graphical mind maps (Fig. E.2). They present a set of competencies without definitions or descriptions. Still, a tabular form allows the inclusion of descriptions (Fig. E.3) even though definitions and descriptions could also be provided in the textual content (Fig. E.4).

To increase informative content, the models present different structural choices. Competencies were, for example, structured by categories, both in tables, text, and graphic representations, exemplified by a multi-level list (Appendix E, Fig. E.5). Relative importance was simply presented in tables (Fig. E.3) and statistical charts (Fig. E.4).

Regarding more detailed elements, competency models were structured by row, column, and other headings in tables (Fig. E.8) as well as by basic shapes, text boxes, fonts, lines, arrows, and colors in hierarchic representations (Fig. E.10). Job roles were typically connected to expertise levels. Then, job roles, competencies, and their expected levels were embedded into two-dimensional tabular representations (Fig. E.8, E.9). Generally, these levels of expertise and relative importance were presented by percentages (Fig. E.6), means (Fig. E.7), scales (Fig. E.8, E.9), and pictograms (Fig. E.11) in tables as well as by colors and bolding in a graphic list (Fig. E10). Several competency models represent two dimensions. Along with tables (Fig. E.8, E.12), there was also a graphic representation with crossing dimensions (Fig. E.13).

In the end, all the competency models are not independent and self-explanatory. Some competency models consist of several representations, for example, multiple tables [P9, P11], or table and graphics [P8]. Sometimes, understanding also requires familiarization with the text. Generally, competency models range from simple listings to more detailed and polished representations.

4.5. Overview of competency model construction

As seen in the previous sub-sections, the construction of the competency model involves several fundamental, conceptual, methodological, and representation choices. The findings are collected in Table 13 and illustrated with examples chosen from studies.

The identified competency models represent broad and limited application domains and job roles, as summarized in Table 13. Their practical use scenarios enable multiple benefits for different beneficiaries: practitioners, graduates, students, jobseekers, organizations, academia, and community.

The primary studies also demonstrated a varying utilization of concepts and types on which the study can be built. Competency was the most typical choice whereas type varied considerably, for example, from essential and the most important to critical and required.

Representation choices reflect the level of detail in the content of the model. The competency models demonstrate different one- or multi-level or -dimensional categorizations employing diverse technical and soft, conceptual, and application domain specific categories. Regarding levels of expertise, studies demonstrated the utilization of different ordinal and nominal scales in addition to that statistical descriptives were used to indicate the importance of the competency among subjects and sources. The studies also represent a varying granularity, i.e., handling competency areas as a single, high-level concept or chopped into multiple sub-competencies. Definitions and descriptions of competencies take different forms and places and reflect different theoretical and practical contexts. The choices manifest in the appearance that comprised mainly tables but also graphic, chart, and textual representations.

Methodologically, the primary studies relied mainly on qualitative methods, interviews, literature reviews as well as varying analysis methods, even though quantitative methods were also employed. Actual research strategies such as ethnography and case study were rarely defined. The studies collected competencies from human participants and a wide range of existing literature.

Table 13 also highlights the identified international aspects, marked with asterisk. In addition to that internationality can be considered in the content of the competency model, international aspects can be considered in the model construction process. Internationality can emerge from the context and aim of the study. Moreover, one primary study employed a high-level context-specific 'Internationality Community' category. Mainly, internationality was explicitly visible when choosing subjects from industry, community, and academia. Some participants represented international and multinational companies as well as different geographic locations in different countries and continents. Competencies were, to a narrow extent, identified from international curricular guidelines and frameworks.

Table 13 can function as a supporting framework for constructing new competency models.

5. Discussion

The purpose of the study was to identify and analyze SE competency models presented in scientific literature. The focus was on the purposes and construction of the model as well as on communication, collaboration, intercultural, and language competencies with respect to the international context. We identified 29 SE competency models.

Regarding RQ1, competency models are created for multiple beneficiaries and use scenarios in a diverse range of application domains in SE. The models benefit industry, academia, community, and individuals through multiple use scenarios. The information about competency requirements facilitates students', jobseekers', graduates', and practitioners' individual improvement and career advancement, organizational staff management and recruitment, and educational content planning and teaching. A competency model offers a view on an application domain, from general SE-related to specific, limited, and job role -specific domains.

Competency models are mainly constructed with the primary aim of defining competency requirements even if competency models also emerge as secondary outcomes of the more extensive research endeavors. Competency models suit and serve different research purposes and practical applications even if this manifoldness may, partly, be attributed to the extensiveness of our approach to them. Most often, the models aim at holistic view, encompassing both technical and soft competencies; the models dedicated solely to soft competencies are rare.

Regarding RQ2, we identified an extensive collection of

communication, collaboration, intercultural, and language competencies. These manifold competencies comprise diverse fundamental forms and expectations for communication, manifest forms of oral and written communication and social interaction. Collaboration competencies exhibit various manifestations of characteristics of the collaborator, agile principles, working together, collaborative actions, leadership functions, independence, functions of agreement and disagreement, and forming spirit. The identified intercultural and language competencies represent a more fragmented collection of aspects, due to their low representation in the competency models. Despite the low number of the competency models that identified cultural needs, this study, however, brings up significant cultural topics: cultural awareness and understanding, different styles of communication, global citizenship, respect for cultures, value diversity, and workplace diversity. The important finding was that all competency models, indeed, incorporate communication and collaboration / teamwork competencies whereas only a few models encompass intercultural and language competencies.

The findings related to communication and collaboration are consistent with prior research (Matturro et al., 2019; Niva et al., 2023) and curricular guidelines SWECOM, SE2014, SWEBOK, and CC2020 (ACM and IEEE Computer Society, 2020; IEEE Computer Society, 2024, 2014; IEEE Computer Society and ACM, 2015). Importance of communication and collaboration is largely recognized, embodying as core components in competency models in contrast to intercultural and language competencies that are depreciated. The findings related to intercultural and language competencies are unaligned with the demands of the international environment where intercultural and language competencies play a central role (Louhiala-Salminen and Kankaanranta, 2011; Ortiz-Marcos et al., 2020; Rajprasit and Hemchua, 2015; Hernández Pozas et al., 2020; Sarwari et al., 2024; Warnick, 2010). In fact, the results remind us of employers' expectations presented in job ads; employers ignored cultural aspects even though language proficiency demands were largely presented (Niva et al., 2023).

Intercultural competencies play a central role in the international environment (Ortiz-Marcos et al., 2020; Warnick, 2010) although this study hardly addresses them. However, curricular guidelines (ACM and IEEE Computer Society, 2020; IEEE Computer Society, 2024, 2014; IEEE Computer Society and ACM, 2015) address cultural sensitivity, global diversity, cultural awareness, multicultural elements, and teams consisting of people from diverse cultural backgrounds — still, with a varying slight emphasis. This study demonstrates that intercultural competencies – much like language proficiency – do not belong to the core components of the competency models. A possible explanation for this result might be the limited awareness and consideration of international or global dimensions among primary studies. Additionally, the homogenous or monocultural nature of the work environments represented by the research subjects may have contributed to the absence. Given that culture and language have been identified as major barriers to global collaboration (Noll et al., 2010), it would be reasonable to expect these aspects to emerge in data if they were adequately recognized or present in the studied contexts.

In the end, this SLR uplifts intercultural competencies more than prior research (Matturro et al., 2019; Niva et al., 2023) albeit the incorporation of intercultural competencies into the competency models seems to be incidental. Overall, this study hints that language and intercultural competencies are raised more frequently in the studies related to education, student subjects, and inherently international domains, further suggesting that the presence of one can imply the other.

To some extent, language proficiency may be taken for granted or considered inherent. The explicit language demands may have been replaced by generalizations such as 'communicate orally and in writing in different settings' as demonstrated in [P13] where the need for English proficiency was identified by the research subjects, i.e., students but excluded from the model. In fact, the lack of languages is aligned with the missing emphasis on languages in the international frameworks and curricular guidelines. Yet, SWECOM (IEEE Computer Society, 2014) refers to international accessibility, languages, and cultural considerations, and SWEBOK (IEEE Computer Society, 2024) regards communication in the native language as beneficial with teammates. Perhaps, curricular guidelines focus on a more limited context.

As RQ2 revealed, communication and collaboration / teamwork embody as core components in SE competency models whereas intercultural and language competencies are largely depreciated. The consideration of this result may initiate an important – academic or societal – discussion on the importance of intercultural communication aspects. Existing SE competency models have not supported the inclusion of intercultural communication competencies in curricula. Ignorance may also have led to underrating in recruitment and team formation in the international SE organizations.

The results through the identified collections of communication, collaboration, intercultural, and language competencies may help us to understand the diversity of competencies required in the international workplaces where people from different nationalities and cultural and linguistic backgrounds collaborate. From the perspective of education, these collections of competencies contribute to curriculum and course development, hints an individual on important competencies in the international SE context, and helps SE organizations identify competencies that can improve performance and productivity in their own environments. Furthermore, the vast collections of identified communication and collaboration competencies can be utilized in language learning; they represent activities that may need to be completed in a foreign language in an international workplace.

RQ3 revealed that competency models are constructed using diverse mono- and multi-, quantitative and qualitative data collection and analysis methods on a varying conceptual basis. The identified competency models represent considerable methodological diversity with various mono- and multi-method approaches. Despite the emphasis on the qualitative method, the primary studies employed rather different data collection methods, from informal conversations to rigorously defined SLR and Delphi. The most popular methods were interview, literature review, and questionnaire / survey. Diversity appears also in research strategies, analysis methods, and the utilization of human and written sources. Data were collected – independently or in combination – from a few to hundreds of software industry practitioners, students and graduates, contributors, and conference participants as well as from scientific literature, international curricular guidelines, bodies of knowledge, and job ads.

Methodologically, there was no significant change to Assyne et al. (2022b). However, the prior methodological emphasis on the job ad studies (Matturro et al., 2019) shifted towards interviews and questionnaires. In fact, there is methodologically considerable potential for further research as the primary studies ignored many potential sources such as customers and suppliers, training calendars, appraisal forms, organizations' visions and missions, and planning documents (Sanghi, 2016).

Fragmentation appears on the conceptual basis even though more than half of the primary studies employed the concept of 'competency,' albeit either as defined, undefined, a synonym for other terms, or side-by-side with others. Concepts seem to be taken for granted and exemplify the problematic conceptual fragmentation (Pikkarainen, 2014). On the other hand, the lack of unity can reflect the conceptual bases in curricular guidelines and existing frameworks (ACM and IEEE Computer Society, 2020; European Commission, n.d.; ICT-mastery.eu, n.d.; IEEE Computer Society, 2024, 2014; IEEE Computer Society and ACM, 2015; IT Professionalism Europe, n.d.) even if they serve different purposes — just like the identified competency models. Despite the diversity in concepts, the studies result in consistent findings conveying various perspectives on the needs.

Eventually, a competency model is constructed through a series of choices including, e.g., decisions about the final appearance, detailedness through granularity and competency definitions, the job roles they aim to represent, the way expertise levels are articulated, application

domain, and competency categorizations. The fundamental and representation decisions shape the available options for the outcome and guide the entire construction process. The simplest competency models are brief bulleted lists or graphic mind maps and, thus, easy to comprehend whereas the models that include a more detailed set of competencies at a profound granularity level provide nuanced understanding of the required professional capabilities. According to the most dominant characteristics of model construction, competency models are based on the 'competency' concept; constructed using qualitative research method and through multiple data collection and analysis methods; represented as a tabular format, rely on the technical and soft competency categories with variation, attach descriptions or definitions of the competencies, and utilize both empirical and literary sources for competency identification.

These findings related to different fundamental, conceptual, representation, and methodological choices can help us understand the process of competency model construction. We consider these results, in conjunction with RQ1, valuable for curriculum designers and future researchers who are developing their own competency models. Especially Table 13, a summary of identified elements in the competency model construction, can smoothen the development process. The broad view on competencies can extensively support academia and facilitate the development of the entire academic program or identification of individual strengths and areas for holistic improvement whereas more limited models support single courses and training in a specific area. Opting for higher granularity with manifold sub-competencies with detailed descriptions and definitions can provide content for a more detailed course design.

Regarding the specific focus area of the study, internationality was scarcely represented explicitly — despite the internationality of the SE field. It seems that internationality is neither a predominant characteristic in the construction nor in the content of the competency model. Only a few primary studies defined their aim or context accordingly. A minimal role emerged also in rare explicit internationality mentions in the content of competency models. Still, some studies collected data from participants across various geographic locations on several continents as well as international or multinational companies. The presence of internationality in content is not explained by international research participants. Moreover, a gap in the international alignment can be observed through low occurrences of intercultural and language competencies.

In the end, this study may not answer the question relating to the competency needs of international workplaces. Additional research might be needed. Moreover, the findings of this study provide only limited support for internationalizing academic programs and individuals pursuing a career in an international job position. Perhaps, the absence of international aspects might be explained by the lack of international competency models among the primary studies or by the fact that the data collections for the competency models were conducted in work environments where international exposure and interactions happened less frequently. The findings can, however, help advance dialogue on the effort needed to incorporate internationalization – and intercultural communication – into education, SE industry, and the entire society.

6. Validity discussion

In this section, we discuss the validity of our findings by addressing various aspects of validity.

First, we tested numerous versions of search strings to keep our search string relatively broad to gather as many relevant papers as possible and to prepare for a low relative proportion of relevant papers, observed in (Assyne et al., 2022b). To ensure a wide range of publishers and diverse sources, we chose databases the ACM Digital Library, IEEE Xplore, Scopus, and Web of Science that encompass largely SE literature and related fields. However, we limited our literature search to academic journal publications, conference proceedings, and books.

Second, the relatively low Kappa scores observed during the screening phases – 0.2589 for title screening and 0.3655 for abstract screening prior to conflict resolution – can be attributed to the broad search string used to ensure comprehensive coverage of relevant competency models. This approach likely introduced a wider variety of studies, increasing the likelihood of disagreement between screeners. Additionally, the unestablished nature of competency models and their representations placed greater emphasis on manual interpretation. Stricter inclusion criteria could also have excluded relevant studies while they could have reduced conflicts. Anticipating this, we placed greater emphasis on conflict resolution.

Third, the authors discussed and agreed on the aims of the review and the protocol, before and during the review process. Prior to the actual application of the inclusion and exclusion criteria, the reviewers performed a pilot to improve agreeability. Furthermore, to limit subjective bias, we ensured that each paper was reviewed by two people in the actual title and abstract screening phases. Furthermore, we attempted to mitigate the reviewer bias by regular discussions on the application of inclusion and exclusion criteria in full-text screening, the quality criteria in quality assessment, and data extraction that were performed by the first author.

Fourth, a considerable threat to validity pertains to the definition and scope of what constitutes a competency model. To address this, we defined the main concepts rigorously. After scrutiny, we defined a competency model as a compilation of competencies encompassing also related concepts. To our understanding, competency models provide a holistic view of individually attainable competencies and their importance.

In the end, the findings of this SLR may be influenced by the limited number of the application domains and contexts of the selected competency models. While we attempted to include a diverse set of competency models, the results may not capture emerging competencies in a rapidly evolving field or in the international context. Further research could explore the influence of international workplaces on competency requirements in different application domains.

7. Conclusion

In this paper, we aimed to identify and analyze existing SE competency models and their construction, as well as investigate communication, collaboration, intercultural, and language competencies within these models considering the aspects of internationality. To achieve this goal, we conducted an extensive systematic literature review and chose 29 relevant primary studies for closer inspection.

Our study identified and presented SE-related competency models, their application domains and purposes as well as the elements of their construction. Competency models serve different functions across versatile, broad and limited application domains and provide different stakeholders with multiple use scenarios. The competency models provide information on competency requirements, offer guidance for improvement, and assist software organizations in managing and developing their staff. In practice, competency models benefit jobseekers, students, graduates, practitioners, organizations and their HR management, educators, curriculum designers, and the community. Competency models can emerge as primary and secondary outcomes of research.

Furthermore, we identified and collected an extensive collection of communication, collaboration, intercultural, and language competencies. The importance of communication and collaboration is largely recognized, embodying as core components in SE competency models in contrast to intercultural and language competencies that are depreciated and largely missing from the competency models.

Competency model construction exhibits methodological diversity with various mono- and multi-method approaches in their construction. Competency models are constructed by both qualitative and

quantitative methods, various research strategies, data collection and analysis methods, and with involvement of diverse human subjects and literature. The construction process leading to the final appearance is shaped by the selected application domains and job roles, conceptual basis, incorporation of expertise levels, and categorization and specification of competencies through descriptions and definitions.

Competency models lack international aspects; internationality is neither a predominant characteristic in the construction nor in the content of the competency model. Competency models ignore explicit references to internationality when the aspects innate to scientific research were ignored.

The results of this study are valuable to academia, individuals, and industry stakeholders seeking information on international competencies and practical applications of competency models. The findings can also serve as a foundation for developing new competency models. Especially, curriculum designers can benefit from both the identified models and their synthesized content in addition to that the findings can assist in designing course syllabi. The findings can offer valuable guidance for students, graduates, and job seekers, as well as for companies to develop or manage their staff. Further research could identify and provide a better understanding of the competencies required in international workplaces.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the first author used Microsoft Copilot and ChatGPT to improve the readability and language of the manuscript. After using these tools / services, the author reviewed and edited the content as needed and takes full responsibility for the content of the published article.

CRediT authorship contribution statement

Anu Niva: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jouni Markkula:** Validation, Supervision, Conceptualization. **Elina Annanperä:** Validation, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Table A15

Table A15
Test strings.

1st part	operation	2nd part	operation	3rd part	number of items in ACM Digital Library, IEEE Xplore, Scopus, and Web of Science*
“software engineer*” OR “software develop*” OR “software industr*” OR "software organization*" OR "software project*"	AND	"skill* model" OR "skill* framework"			30
“software engineer*” OR “software develop*” OR “software industr*” OR "software organization*" OR "software project*"	AND	“competenc* model” OR “competenc* framework”			1060
“software engineer*” OR “software develop*” OR “software industr*” OR "software organization*" OR "software project*"	AND	curricul* OR "syllab*"			6979
“software engineer*” OR “software develop*” OR “software industr*” OR "software organization*" OR "software project*"	AND	curricul* OR "syllab*"	AND	"competenc*" OR "skill*"	2447
“software engineer*” OR “software develop*” OR “software industr*” OR "software organization*" OR "software project*"	AND	"model" OR "framework"	AND	"competenc*" OR "skill*"	5921
“software engineer*” OR “software develop*” OR “software industr*” OR "software organization*" OR "software project*"	AND	model OR framework OR profile OR outline	AND	"competenc*" OR "skill*"	7280
“software engineer*” OR “software develop*” OR “software industr*” OR "software organization*" OR "software project*"	AND	model OR framework OR profile OR outline	AND	"competenc*" OR "skill*" OR capabilit*	21,127
“software engineer*” OR “software develop*” OR “software industr*” OR "software organization*" OR "software project*"	AND	"competenc*" OR "skill*"			16,471
“software engineer*” OR “software develop*” OR “software industr*” OR "software organization*" OR "software project*"	AND	“professional competenc*”			175
software develop* OR "software engineer*" OR "software industr*" OR "software organization*" OR "software process*" OR "software product*" OR "software project*" OR "software test*"	AND	"skill* model" OR "skill* framework"			38
software develop* OR "software engineer*" OR "software industr*" OR "software organization*" OR "software process*" OR "software product*" OR "software project*" OR "software test*"	AND	"skill* model" OR "skill* framework" OR "skill* outline"			38

(*continued on next page*)

Table A15 (*continued*)

1st part	operation	2nd part	operation	3rd part	number of items in ACM Digital Library, IEEE Xplore, Scopus, and Web of Science*
software develop* OR "software engineer*" OR "software industr*" OR "software organization*" OR "software process*" OR "software product*" OR "software project*" OR "software test*"	AND	“competenc* model” OR “competenc* framework”			971
software develop* OR "software engineer*" OR "software industr*" OR "software organization*" OR "software process*" OR "software product*" OR "software project*" OR "software test*"	AND	“competenc* model” OR “competenc* framework” OR "competenc* outline"			971
software develop* OR "software engineer*" OR "software industr*" OR "software organization*" OR "software process*" OR "software product*" OR "software project*" OR "software test*"	AND	"competenc* profile"			39
software develop* OR "software engineer*" OR "software industr*" OR "software organization*" OR "software process*" OR "software product*" OR "software project*" OR "software test*"	AND	“capabilit* model” OR “capabilit* framework”			6257
software develop* OR "software engineer*" OR "software industr*" OR "software organization*" OR "software process*" OR "software product*" OR "software project*" OR "software test*"	AND	model OR framework OR profile OR outline	AND	"competenc*" OR "skill*"	10,642
"software design*" OR "software analys*" OR "software team*" OR "software compan*" OR "software firm*" OR "software house*" OR "software system*"	AND	"skill* model" OR "skill* framework"			11
"software design*" OR "software analys*" OR "software team*" OR "software compan*" OR "software firm*" OR "software house*" OR "software system*"	AND	"skill* model" OR "skill* framework" OR "skill* outline"			11
"software design*" OR "software analys*" OR "software team*" OR "software compan*" OR "software firm*" OR "software house*" OR "software system*"	AND	“competenc* model” OR “competenc* framework”			136
"software design*" OR "software analys*" OR "software team*" OR "software compan*" OR "software firm*" OR "software house*" OR "software system*"	AND	“competenc* model” OR “competenc* framework” OR "competenc* outline"			136
"software design*" OR "software analys*" OR "software team*" OR "software compan*" OR "software firm*" OR "software house*" OR "software system*"	AND	"competenc* profile"			7
"software design*" OR "software analys*" OR "software team*" OR "software compan*" OR "software firm*" OR "software house*" OR "software system*"	AND	model OR framework OR profile		"competenc*" OR "skill*"	1989
"software design*" OR "software analys*" OR "software team*" OR "software compan*" OR "software firm*" OR "software house*" OR "software system*"	AND	"capabilit* model" OR "capabilit* framework"			40
"software develop*" OR "software engineer*" OR "software industr*" OR "software organization*" OR "software process*" OR "software product*" OR "software project*" OR "software test*" OR "software design*" OR "software analys*" OR "software team*" OR "software compan*" OR "software firm*" OR "software house*" OR "software system*"	AND	"competenc*" OR "skill*"	AND	model OR framework OR profile	10,475

* Duplicates not removed.

Appendix B

Tables B16, B17

Table B16
List of journals.

Journal Name	Count
IEEE Access	3
Information and Software Technology	2
ACM Transactions on Computing Education	1
IEEE Transactions on Engineering Management	1
IEEE Transactions on Software Engineering	1
IET Software	1
Information Systems Journal	1
International Journal of Human Capital and Information Technology Professionals	1
IT - Information Technology	1
Journal of Systems and Software	1
MIS Quarterly Executive	1
Total	**14**

Table B17
List of conferences.

Conference Name	Count
IEEE Global Engineering Education Conference	2
ACM Conference on Innovation and Technology in Computer Science Education	1
ACM Joint Meeting European Software Engineering Conference and Symposium on the Foundations of Software Engineering	1
ACM/IEEE International Symposium on Empirical Software Engineering and Measurement	1
Conference of the South African Institute of Computer Scientists and Information Technologists	1
IEEE Conference on Software Engineering Education and Training	1
IEEE Frontiers in Education Conference	1
IEEE International Conference on Industrial Engineering and Engineering Management	1
IEEE International Requirements Engineering Conference	1
IEEE/ACM International Workshop on Emerging Trends in Software Engineering for Blockchain	1
International Conference on Computer Supported Education	1
International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management	1
International Conference on Software and Computer Applications	1
International Conference on Software and Systems Process	1
Total	15

Appendix C

Table C18

Table C18
Selected Primary Studies.

Paper	Paper
P1	Rivera-Ibarra, J. G., Rodriguez-Jacobo, J., Fernandez-Zepeda, J. A., & Serrano-Vargas, M. A. (2010). Competency Framework for Software Engineers. 2010 23rd IEEE Conference on Software Engineering Education and Training, 33–40. https://doi.org/10.1109/CSEET.2010.21
P2	André, M., Baldoquín, M. G., & Acuña, S. T. (2011). Formal model for assigning human resources to teams in software projects. Information and Software Technology, 53(3), 259–275. https://doi.org/10.1016/j.infsof.2010.11.011
P3	Espinosa-Curiel, I. E., Rodríguez-Jacobo, J., & Fernández-Zepeda, J. A. (2011). A competency framework for the stakeholders of a software process improvement initiative. Proceedings of the 2011 International Conference on Software and Systems Process, 139–148. https://doi.org/10.1145/1987875.1987898
P4	Klendauer, R., Berkovich, M., Gelvin, R., Leimeister, J. M., & Krcmar, H. (2012). Towards a competency model for requirements analysts. Information Systems Journal, 22(6), 475–503. https://doi.org/10.1111/j.1365–2575.2011.00395.x
P5	Saldaña-Ramos, J., Sanz-Esteban, A., Garcia-Guzman, J., & Amescua, A. (2012). Design of a competence model for testing teams. IET Software, 6(5), 405–415. https://doi.org/10.1049/iet-sen.2011.0182
P6	Kimmelmann, N. (2013). Career in Open Source? Relevant Competencies for Successful Open Source Developers. Itit, 55(5), 204–212. https://doi.org/10.1515/itit.2013.1009
P7	Linck, B., Ohrndorf, L., Schubert, S., Stechert, P., Magenheim, J., Nelles, W., Neugebauer, J., & Schaper, N. (2013). Competence model for informatics modelling and system comprehension. 2013 IEEE Global Engineering Education Conference, 85–93. https://doi.org/10.1109/EduCon.2013.6530090
P8	Matook, S., & Maruping, L. M. (2014). A Competency Model for Customer Representatives in Agile Software Development Projects. MIS Quartely Executive, 13(2), 77–95.
P9	Sedelmaier, Y., & Landes, D. (2014). Software engineering body of skills (SWEBOS). 2014 IEEE Global Engineering Education Conference, 395–401. https://doi.org/10.1109/EDUCON.2014.6826125
P10	Aisha, A. N., Siswanto, J., & Sudirman, I. (2016). Competencies model for entrepreneur development in software industries. 2016 IEEE International Conference on Industrial Engineering and Engineering Management, 184–188. https://doi.org/10.1109/IEEM.2016.7797861
P11	Calazans, A. T. S., Paldes, R. A., Masson, E. T. S., Brito, I. S., Rezende, K. F., Braosi, E., & Pereira, N. I. (2017). Software Requirements Analyst Profile: A Descriptive Study of Brazil and Mexico. 2017 IEEE 25th International Requirements Engineering Conference, 204–212. https://doi.org/10.1109/RE.2017.22
P12	Daneva, M., Wang, C., & Hoener, P. (2017). What the Job Market Wants from Requirements Engineers? An Empirical Analysis of Online Job Ads from the Netherlands. 2017 ACM/IEEE International Symposium on Empirical Software Engineering and Measurement, 448–453. https://doi.org/10.1109/ESEM.2017.60
P13	Frezza, S., Daniels, M., Pears, A., Cajander, Å., Kann, V., Kapoor, A., McDermott, R., Peters, A.-K., Sabin, M., & Wallace, C. (2018). Modelling competencies for computing education beyond 2020: A research based approach to defining competencies in the computing disciplines. Proceedings Companion of the 23rd Annual ACM Conference on Innovation and Technology in Computer Science Education, 148–174. https://doi.org/10.1145/3293881.3295782
P14	Vishnubhotla, S. D., Mendes, E., & Lundberg, L. (2018). An Insight into the Capabilities of Professionals and Teams in Agile Software Development: A Systematic Literature Review. Proceedings of the 2018 7th International Conference on Software and Computer Applications, 10–19. https://doi.org/10.1145/3185089.3185096
P15	Gurcan, F., & Cagiltay, N. E. (2019). Big Data Software Engineering: Analysis of Knowledge Domains and Skill Sets Using LDA-Based Topic Modeling. IEEE Access, 7, 82,541–82,552. https://doi.org/10.1109/ACCESS.2019.2924075
P16	Kalliamvakou, E., Bird, C., Zimmermann, T., Begel, A., DeLine, R., & German, D. M. (2019). What Makes a Great Manager of Software Engineers? IEEE Transactions on Software Engineering, 45(1), 87–106. https://doi.org/10.1109/TSE.2017.2768368
P17	Mangiza, P., & Brown, I. (2020). Requisite Skills Profile of Software Development Professionals for Startups. Conference of the South African Institute of Computer Scientists and Information Technologists 2020, 102–109. https://doi.org/10.1145/3410886.3410904
P18	Cornide-Reyes, H., Riquelme, F., Noel, R., Villarroel, R., Cechinel, C., Letelier, P., & Munoz, R. (2021). Key Skills to Work With Agile Frameworks in Software Engineering: Chilean Perspectives. IEEE Access, 9, 84,724–84,738. https://doi.org/10.1109/ACCESS.2021.3087717
P19	Kassab, M., Destefanis, G., DeFranco, J., & Pranav, P. (2021). Blockchain-Engineers Wanted: An Empirical Analysis on Required Skills, Education and Experience. 2021 IEEE/ACM 4th International Workshop on Emerging Trends in Software Engineering for Blockchain, 49–55. https://doi.org/10.1109/WETSEB52558.2021.00014
P20	Kassab, M., Laplante, P., Defranco, J., Neto, V. V. G., & Destefanis, G. (2021). Exploring the Profiles of Software Testing Jobs in the United States. IEEE Access, 9, 68,905–68,916. https://doi.org/10.1109/ACCESS.2021.3077755
P21	Ahsan, K., & Ho, M. (2022). Analysis of Agile Project Manager Competencies From Recruitment Signals. Proceedings of the 15th International Conference on Computer Supported Education, 71, 1–14. https://doi.org/10.1109/TEM.2022.3222037
P22	Assyne, N., Ghanbari, H., & Pulkkinen, M. (2022a). The essential competencies of software professionals: A unified competence framework. Information and Software Technology, 151, 107,020. https://doi.org/10.1016/j.infsof.2022.107020
P23	Assyne, N., Ghanbari, H., & Pulkkinen, M. (2022b). The state of research on software engineering competencies: A systematic mapping study. Journal of Systems and Software, 185, 111,183. https://doi.org/10.1016/j.jss.2021.111183
P24	Goh, J. E. E., Mojado, C. V., & Manaligod, H. J. T. (2022). Competency Model for Programming Courses in Information Technology Education (ITE) Programs from Industry Perspective: A Delphi Method. 2022 IEEE 14th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management, 1–6. https://doi.org/10.1109/HNICEM57413.2022.10109471
P25	Hidayati, A., Budiardjo, E. K., & Purwandari, B. (2022). Scrum Team Competencies in Information Technology Professionals in the Global Software Development Environment: International Journal of Human Capital and Information Technology Professionals, 13(1), 1–21. https://doi.org/10.4018/IJHCITP.293233
P26	Liang, J. T., Zimmermann, T., & Ford, D. (2022). Understanding skills for OSS communities on GitHub. Proceedings of the 30th ACM Joint European Software Engineering Conference and Symposium on the Foundations of Software Engineering, 170–182. https://doi.org/10.1145/3540250.3549082
P27	Akdur, D. (2023). Analysis of Software Engineering Skills Gap in the Industry. ACM Transactions on Computing Education, 23(1), 1–28. https://doi.org/10.1145/3567837
P28	Bona, F., Chanin, R., Nascimento, N., & Sales, A. (2023). Understanding the Gaps in Software Engineering Education from the Perspective of IT Leaders: A Field Study: Proceedings of the 15th International Conference on Computer Supported Education, 511–518. https://doi.org/10.5220/0011959100003470
P29	Suleiman, A. D., Hou, D., Liu, Y., DeWaters, J., Small, M. M., De Souza, J. G., & Shepherd, D. (2023). Mapping Learning Objectives of Project-Based Undergraduate Software Engineering Courses to CC2020 Competency Model. 2023 IEEE Frontiers in Education Conference, 1–8. https://doi.org/10.1109/FIE58773.2023.10342967

Appendix D

Table D19

Table D19
Applied Methods in Primary Studies.

	Method			Strategies					Data Collection										Analysis						
NR	mixed	qualitative	quantitative	grounded theory	case study	Delphi	ethnography	action research	interview	literature	survey	questionnaire	job ads	documents	observation	SLR	focus group	informal conversations	descriptive statistics	qualitative analysis	content analysis	thematic analysis	inferential statistics	natural language processing	functional analysis
P1		x		x			x		x			x			x										x
P2	x					x					x														
P3	x			x	x		x	x	x	x		x			x										
P4		x							x												x				
P5	x									x	x						x		x						
P6		x		x					x												x				
P7		x							x	x				x							x				
P8		x							x											x					
P9		x		x					x									x		x					
P10		x							x	x										x					
P11	x									x			x						x	x	x		x		
P12	x												x						x			x			
P13		x			x						x											x			
P14	x															x			x	x					
P15	x												x						x		x			x	
P16	x								x		x	x							x	x			x		
P17	x					x			x	x		x							x	x					
P18	x								x		x								x	x					
P19	x												x						x	x				x	
P20	x												x						x	x				x	
P21	x									x			x						x		x				
P22	x								x	x							x				x				
P23	x															x			x		x				
P24	x					x			x			x							x			x	x		
P25	x								x	x		x					x		x		x				
P26	x									x	x								x	x					
P27			x						x		x								x				x		
P28		x							x												x				
P29		x			x									x								x			
total	18	10	1	4	3	3	2	1	16	10	7	6	6	2	2	2	3	1	16	11	10	4	4	3	1

Appendix E

Figs. E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13

Graphic Model Library*.

Develop and manage large IT systems
Work in groups in different settings
Communicate orally and in writing in different settings
Learn independently and efficiently
Learn from mistakes and hare knowledge
Reflect on and evaluate your work
Reflect on ethics, gender, and inclusiveness
Show self-discipline and take responsibility
Reflect on ethics, gender, and inclusiveness
Show self-discipline and take responsibility

Fig. E1. Tabular, list [P13].

Fig. E2. Graphic, mind map [P28].

Skill	Description
Good oral communication	Carry out situation reports Conduct interviews / meetings with users
Good written communication	Producing Requirements Documentation Prepare meeting record
Teamwork	Manage integrations with other systems Leading developers team

Fig. E3. Tabular, descriptions [P11].

4.2 Social Competencies. The Social Competencies permit SPI stakeholders to interact, collaborate, and work with others, to handle the interpersonal relations, and to construct new forms of cooperation. We divide the personal competencies in the following three subcategories.

1. Interpersonal relation. SPI stakeholders need to initiate, support, and handle personal relations with friends, colleagues, teammates and clients. These competencies suppose that individuals can respect and appreciate the values, beliefs, cultures, and histories of others. These competencies help to create an environment in which stakeholders feel welcome and included, and in which they can grow up. Some examples of these competencies are communication, interpersonal sensitivity, and politeness.

2. Work in team. An SPI initiative requires stakeholders to work cooperatively as a ...

Fig. E4. Textual [P3].

Self-organized working processes
Social:
- Active communication skills
- "E-mail-competency"

Personal:
- Openness to new things and approaches

International Community
Social:
- Intercultural competencies
- English language skills
- Dealing with different styles of communication

Fig. E5. Tabular, multi-level list [P6].

Professional and Foundational Knowledge	
Name	Percentage
Oral Communication & Presentation	64.52 %
Written Communication	64.52 %
Problem-Solving and Troubleshooting	12.90 %
Project and Task Organization and Planning	93.55 %
Collaboration and Teamwork	90.55 %
Ethical and Intercultural Perspectives	23.58 %

Fig. E6. Tabular, percentages [P29].

Fig. E7. Statistical chart [P24].

	Generic Competences									Technical Com	
Fixed Roles	Teamwork and Cooperation	Analytical Skills	Planning and Organization	Negotiation Skills	Adaptability (Flexibility)	Oral Communication Skills Written Communication Skills	Continuous Learning Agility	Language Proficiency Programming Language Proficiency	Modeling Tool Proficiency	...	
Analyst	2	2	2	2	2	2	2	2	1	2	
Designer	2	2	2	1.5	2	2	2	2	2	2	
Programmer	2	2	1	1	2	1	1	2	1	2	2
Project Leader	2	2	2	2	2	2	2	2	1	2	

Fig. E8. Tabular, roles and levels [P2].

Key Skills	Level 2	Level 3
Effective Communication	Scrum Master Team	Product Owner
Collaboration	Product Owner Team	Scrum Master
Teamwork	Product Owner Scrum Master	Team

Fig. E9. Tabular, job roles and levels of expertise [P18].

(*continued on next page*)

(*continued*)

Soft Competences - Social	Interpersonal Relation	**1) communicate to the outside world 2) sociable** 3) communication skills 4) adaptability 5) human skills 6) interpersonal skills 7) social skills 8) contributing to the society
	Cooperation and Work in a Team	**9) knowledge transfer 10) see the bigger picture 11) leadership** 12) teamwork 13) team organizer 14) approachable 15) open and communicating 16) learn from others 17) voice your own opinions 18) cooperation 19) maturity 20) teach and share knowledge
	Handling and Solving Conflicts	**22) humbleness 23) customer awareness 24) understand customer needs** 25) meeting skills 26) contact with clients 27) listening ears 28) compromise 29) empathy
sonal	Development	**30) unafraid 31) creative and brave 32) think outside the box** 33) persistence 34) flexible 35) versatile 36) focus 37) accuracy 38)

Fig. E10. Graphic list; colors, bolding, and levels [P22].

	Literature	Survey
Kind. Empathizes with others and show kindness	[12], [29], [34], [38], [47]	↑ ↑ ↑
Communication. Clearly communicates with others in written and oral forms	[6], [12], [29], [31], [34], [38], [47]	↑ ↑ ↑ ↑ ↑
Asking for help. Knows how to ask for help when one needs it	[29], [38]	↑ ↑ ↑ ↑ ↑
Giving help. Actively helps others when they need it; mentors, guides, or teaches others in the team	[6], [16], [29], [31], [34], [38]	↑ ↑
Conflict resolution. Resolves conflicts between people	[29], [34]	↑
Collaboration. Works with people from diverse backgrounds to achieve a shared goal	[29], [31], [34], [38]	↑ ↑ ↑ ↑

Fig. E11. Tabular, pictograms [P26].

Least Demand	self-organization negotiation self-learning ability conflict resolution	multiple project coordination delivery within time, budget, and quality
Moderate Demand	leadership	quality and customer focus work with product owner to maintain backlog
High Demand	Teamwork Effective communication	agile delivery and implementation experience stakeholder management
	Personal	Practice

Fig. E12. 2-dimensional, expertise levels and categories [P21].

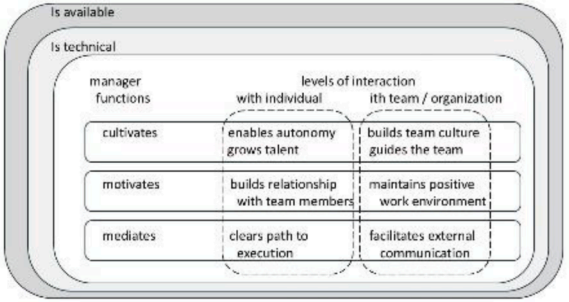

Fig. E13. graphic, crossing dimensions [P16].

*Extracts from the competency models, modified from the original competency models

Data availability

The authors do not have permission to share data.

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