Software Engineering Competency Challenges

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Abstract. Context*: Competent practitioners are the most critical factor in accomplishing Software Engineering's (SE) purpose of building and sustaining high-quality software.* ***Challenges****: The demand for competent SE professionals grows faster than academia and industry's capacity to teach and develop these professionals. There is a discrepancy between the competencies obtained by SE graduates and those required by different domains of the software industry. Conflicts and misuse of SE competency elements and concepts hinder cooperation in the SE community. The simplistic view of human factors related to SE competency hampers its application in SE education, research, and industry communities.* ***Implications****: A profound and consensual understanding of SE competency can accelerate SE professionals' training and direct them to meet the software industry's needs. Theories and practices based on a uniform construct can improve software quality and increase teams' productivity.*

1. Introduction

Human work quality is the central issue for the effectiveness of results in Software Engineering (SE). However, there is a discrepancy between the SE competency demanded by the software industry and that provided by SE education, leading to a long learning curve before professionals become productive [Ouhbi and Pombo 2020, Assyne et al. 2022b, Cazalas et al. 2024]. Moreover, the demand for competent professionals grows much faster than the capacity of academia to form these professionals and for industry to adapt their competency to its specific needs [Garousi et al. 2020].

Advancements in SE competency are limited by the need for precise definitions for its cornerstone concepts [Assyne et al. 2022b]. SE community still needs a consensual *SE competency construct* to avoid misuse of existing terms or creation of redundant terms. Scientific research must establish precise language to allow the elements of a phenomenon to be clearly understood and to demonstrate its factual truth. SE competency needs consensual criteria for assessing the scientific validity of theories so that hypotheses can be empirically tested and proven by objective observation or experiment.

The lack of conceptual consensus on the essence of the SE competency, especially its human factors, leads to heterogeneous operational definitions, hindering the formulation of meaningful interdisciplinary theories and their application to practice. A better understanding of the SE competency construct will enable the advancement of SE education, speeding up the training of students and professionals to understand and meet software industry needs. Besides the social and economic benefits, this may significantly impact SE student's and practitioners' mental health, motivation, and productivity.

2. The Need for a SE Competency Construct

A construct is a conceptual tool encompassing hypotheses and properties applicable to entities in a given realm and providing shared interpretations that foster a sense of unity and purpose in the scientific community. Constructs are cornerstones of science, explaining observable phenomena and enabling the translation of theoretical concepts into practical solutions concerning observable and measurable variables. SE Competency is a construct that must be uniformly and precisely defined to allow educational, academic, and industry organizations to collaborate on strategies to improve SE students' formation and SE professionals' work performance. This construct is essential for (a) establishing a consensual language for SE academics, educators, and professionals; (b) building models and understanding, communicating, and engineering the complex problems involved in SE competency; and (c) exploring all the dimensions of SE competency and their impacts on SE professionals and organizations.

To accomplish these goals, the construct must eliminate conceptual gaps in SE competency definitions, aligning models to address scientific, social, and economic challenges in this area. It must also provide common terminology and concepts that can be applied and interpreted in the same way by any member of the SE community, establishing a uniform operational definition of SE competency, i.e., a procedure that attaches a precise meaning to SE competency by specifying how it is applied and measured within a specific context. Moreover, the construct must deal with synonymy and polysemy phenomena [Chaleplioglou et al. 2020] that hamper SE competency definitions. The word "competency" is polysemic, with various imprecise, ambiguous, and contradictory meanings, opening possibilities for different interpretations. For instance, the American competency approach focuses on individual capabilities, while the European approach includes social and methodological issues and emphasizes the application of competencies in various contexts [Kiesler 2024]. On the other hand, multiple terms, such as proficiency, ability, capability, and skill, are often used as synonyms of competency, bringing inaccuracies and compromising the understanding of the concepts.

The principal feature of the construct, however, is that it must address the fundamental interests and concerns of the SE community, defining and evaluating SE competencies according to the peculiarities of SE domains and organizations. **SE research** concerns deal with conflicts on theoretical foundations of competency that lead to imprecise and contradictory SE competency models and hampers the evolution of consensual theories [Saldaña-Ramos et al. 2012, Sedelmaier and Landes 2015, Assyne et al. 2022b]. From a **SE education** perspective, concerns include a long learning curve for acquiring SE competencies; high divergence on SE courses curricula [Zorzo et al. 2017, ACM-IEEE 2020, Impagliazzo et al. 2020]; lack of models for full competency development [IEEE 2014, Portela 2017, Ouhbi and Pombo 2020] and for objective definition and assessment of SE competencies in higher education [Colomo-Palacios et al. 2013, Assyne et al. 2022a]; and discrepancies between competencies demanded by industry and those acquired by SE students [Ouhbi and Pombo 2020, Garousi et al. 2020, Cico et al. 2021, Cazalas et al. 2024].

SE industry interests are related to the misalignment of technical and soft skills of SE practitioners [Sedelmaier and Landes 2015, Ouhbi and Pombo 2020]; the competency blackout in key SE roles and several industry domains [Holtkcamp et al. 2015, Calazans et al. 2017]; and the difficulty for SE professionals to keep their competencies up to date [SEI 2009, Colomo-Palacios et al. 2013, SOFTEX 2016]. The joint competencies of team members constitute the organizational competency to develop complex software. Therefore, a critical issue for the industry is the coordination of these competencies, but excessive technical focus diminishes this non-technical competency. SE competency management encompasses defining, selecting, building, assessing, developing, applying, improving, and coordinating SE professionals', teams', and organization's competencies. However, despite its fundamental impact on SE results, SE competency models still need to address SE competency management appropriately. SWECOM, for instance, considers management a related discipline, not a specific SE competency, and therefore does not define the SE management competencies [IEEE 2014]. Due to this lack of a multidisciplinary vision of SE competency, the management of SE competency in the industry has historically been carried out by former technical leaders who need proper management education and soft skills development to become competent managers.

3. Fundamentals for a Unified SE competency Construct

Competency must be associated with high performance in work situations, aligned with specific objectives or results, and evaluated at both professional and organizational levels. SE competencies must be directed towards SE's primary concerns of producing quality software within time and budget constraints. Thus, the SE competency construct must focus on a specific purpose: to empower SE professionals to perform better, build and sustain better-quality software products, and generate benefits for themselves and their organizations. Software stakeholders must perceive the quality of products competent SE professionals generate. Therefore, SE competency can be quantified by the extent to which an SE professional or organization, working in a specific context, meets or exceeds stakeholders' needs to achieve specified results. This means that competency is not a quality present or absent in a person but a spectrum of values into which a person can fit.

Figure 1 uses E-R Model notation (extended with *aggregation* to treat a relationship set as an entity set, allowing its participation in other relationships) to show an overview of essential elements of the SE competency construct. Some elements, such as knowledge, skills, and attitudes, are commonly cited in literature. However, they must be detailed to elaborate a scientific construct so that concepts are clear, representative, specific, and likely to be observed and accepted by the research community.

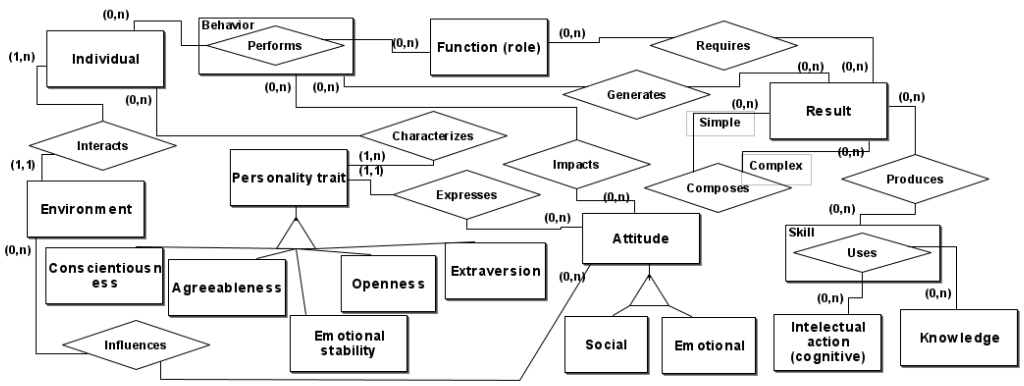

Figure 1. Fundamental elements of SE Competency

The construct must define personal and contextual properties and qualities that can contribute to a SE professional's competency. Knowledge concerns content and information one possesses (*knowing what or about* something). Individual SE knowledge comprises requirements, concepts, standards, models, theories, and tools that must be used in coordination to produce desired results. Skill is related to one's ability to act on (use, apply, manipulate, or transform) something (*knowing how* to do it). An SE skill is defined by cognitive, intellectual actions that manipulate specific SE knowledge. The cognitive actions that manipulate knowledge are organized into six levels according to Bloom's taxonomy. A given element of knowledge can be manipulated by cognitive actions depending on the cognitive development obtained in its learning process.

Attitude represents feelings or emotions, motivated by social concepts or judgments, that induce specific behavior (*knowing how to be*). Although often cited as an essential competency element, *attitude* needs more elaboration in SE competency models. SWECOM, for instance, barely discusses behavioral attributes and provides some generic examples without explaining their connection to the technical competencies deeply covered in the model [IEEE 2014]. Attitude impacts behavior and is built by an individual's interaction with the environment. In some contexts, a person's attitude and behavior may show inconsistencies. The alignment of behavior and attitude depends on intrinsic and extrinsic factors. Among the intrinsic factors, personality traits, such as extraversion and agreeableness, are essential as dispositional factors. The extrinsic aspects influencing behavior are related to the organizational environment, comprising its values and culture [Akpa et al. 2021], social norms, external pressures, and specific task demands.

This preliminary SE competency construct model covers an individual's personality and cognitive, and emotional aspects associated with functions in a work position. These are usually neglected aspects despite their decisive influence on an SE professional's performance. In addition, it articulates knowledge with action to form a skill (i.e., capacity) to execute an action. The coordination of skill and behavior (driven by attitudes) produces a (software) result. This core model emphasizes that a competent SE professional must express knowledge, attitudes, and skills through a software product or service driven by predefined stakeholders' demands. Much research effort is needed to complete this construct so that it fully represents the complex concepts involved in SE competency.

4. Final Remarks

An SE competency construct covers several areas, including organizational culture and administration, educational and vocational training and performance assessment, and psychological and sociological characteristics of human behavior. This heterogeneous confluence contributes to the complexity of defining precise semantics for concepts, hindering the proposition of practical solutions to critical SE competency challenges, such as: competency attitudinal and behavioral aspects and their application to the SE education agenda [Assyne et al. 2022b, Santos et al. 2023]; aligning SE professionals' competencies to address the industry needs [Baker et al. 2021, Cico et al. 2021]; resolving SE teams' technical and non-technical SE competencies gaps [Sedelmaier and Landes 2015, Assyne et al. 2022b]; defining reliable SE competency models and frameworks [Baker et al. 2021, Assyne et al. 2022a]; and managing and assessing SE competencies [Fauzan et al. 2023, Cazalas et al. 2024].

These challenges stem from a shared vision of the SE competency construct, and the availability of the following key results can track their progress:

- Consensual and cohesive SE competency theories and models based on a uniform scientific construct.
- Improved communication and collaboration among SE education, research, and industry communities.
- Complete (technical and non-technical) development of SE professional competencies based on homogeneous SE education curricula.
- Effective management (definition, selection, assessment, development, application, and improvement) of SE competencies for teams and organizations.
- Objective methods for defining and assessing SE competencies needed for an SE work position.
- Efficient training and development of competent SE professionals to meet the SE industry demand.

Improving SE competency generates economic and social benefits for society through industry workforce improvement and higher-quality products. This paper shows the importance and the challenges of dealing with precise SE competency concepts, highlighting the limitations of current SE competency definitions, and briefly introducing core elements for a SE competency construct. A significant challenge for the SE community is fully developing a well-defined, consensual, and measurable SE competency construct, articulating cognitive and emotional capabilities to create high-quality software.

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