Software Engineering Education Knowledge versus Industrial Needs

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Abstract—Contribution: Determine and analyze the gap between software practitioners' education outlined in the 2014 IEEE/ACM Software Engineering Education Knowledge (SEEK) and industrial needs pointed by Wikipedia articles referenced in Stack Overflow (SO) posts.

Background: Previous work has uncovered deficiencies in the coverage of computer fundamentals, people skills, software processes, and human-computer interaction, suggesting rebalancing.

Research Questions: 1) To what extent are developers' needs, in terms of Wikipedia articles referenced in SO posts, covered by the SEEK knowledge units? 2) How does the popularity of Wikipedia articles relate to their SEEK coverage? 3) What areas of computing knowledge can be better covered by the SEEK knowledge units? 4) Why are Wikipedia articles covered by the SEEK knowledge units cited on SO?

Methodology: Wikipedia articles were systematically collected from SO posts. The most cited were manually mapped to the SEEK knowledge units, assessed according to their degree of coverage. Articles insufficiently covered by the SEEK were classified by hand using the 2012 ACM Computing Classification System. A sample of posts referencing sufficiently covered articles was manually analyzed. A survey was conducted on software practitioners to validate the study findings.

Findings: SEEK appears to cover sufficiently computer science fundamentals, software design and mathematical concepts, but less so areas like the World Wide Web, software engineering components, and computer graphics. Developers seek advice, best practices and explanations about software topics, and code review assistance. Future SEEK models and the computing education could dive deeper in information systems, design, testing, security, and soft skills.

Index Terms—Software engineering education, curriculum models, Stack Overflow, Wikipedia.

I. INTRODUCTION

VER the last decades a lot of research has dealt with the lack of university curricula focused on software engineering (SE). In 1999, Hilburn and Bagert [1] stressed the need for creating a contemporary SE curriculum model, characterizing such a design as challenging, due to the field's immaturity at the time. For this purpose, they proposed a model for designing SE curricula. Earlier, Hilburn *et al.* [2] had examined the integration of SE principles into undergraduate computer science programs, proposing a structure integrating eight fundamental software concepts in computing curricula with SE tracks.

SE is closely related with the computer science and computer engineering disciplines. According to the latest

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IEEE/ACM Curriculum Guidelines for Undergraduate Degree Programs in Software Engineering (SE2014) [3], SE curricula are usually developed by Departments of these two disciplines, and include a combination of computer science, engineering, and management science courses—this distinguishes them from typical computer science programs.

Based on this, proposed SE curricula combine material from adjacent education areas to provide SE practitioners with well-rounded knowledge. In the seventies, Freeman *et al.* [4] presented the essential elements of SE education: computer and management science topics, communication skills, problem solving, design methodologies. Later, a structure for graduate degree programs was introduced by Freeman and Wasserman [5], balancing fundamental and specialized SE topics, due to the difficulty of fitting all required material in undergraduate programs. Jensen *et al.* [6] combined elements from computer science and engineering, management science, communication and problem solving. More recently, Cowling [7] presented a multi-dimensional model for producing various curricula for computing and SE.

Researchers examine how university curricula can better prepare software practitioners. In the late nineties, Lethbridge [8] surveyed software developers to identify important SE and computer science topics adapted from the IEEE/ACM Software Engineering Body of Knowledge (SWEBOK) [9], concluding that there is significant room for improvement in what is taught to SE students. The survey results influenced the design of the first SE program in Canada, at the University of Ottawa. Mathematics and engineering subjects were assessed as the least memorable, as opposed to software topics which were found the most memorable. Certain typically compulsory subjects including differential equations and numerical methods were found to be of low importance, and were turned to optional in the particular program. The author suggests that more emphasis should be given to the components of testing and quality assurance, requirements analysis, project management, and configuration management—these are usually optional or receive less attention. The study was repeated in 2000, again concluding that traditional engineering courses such as linear algebra, differential equations, and calculus are overtaught, while more demanded SE courses are inadequately covered [10]. Less weight should be placed on traditional courses, and more on people skills, software processes, humancomputer interaction.

Studies recommend tighter collaboration between academia and industry to better prepare trainees to meet industrial demands. To train students and improve their ability of real-world problem solving, in the mid 2000s, Reichlmay [11]

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encouraged closer collaboration between academia and the SE professional industry. Bollin *et al.* [12] proposed using a simulation program to help participants familiarize with regular tasks of professional software engineers. A team-alternation methodology was suggested by Walker and Slotterbeck [13] to assist undergraduates in dealing with complications occurring when working for years on the same SE project.

Industrial needs for SE professionals are continuously increasing. In 2012, Moreno *et al.* [14] examined the IEEE/ACM 2004 Software Engineering [15] and 2009 Graduate Software Engineering [16] curriculum recommendations to evaluate whether undergraduate courses effectively cover the market's growing needs. They found gaps in the de facto courses, particularly in the ones that tackle business-oriented topics (*e.g.*, IT Business Consultancy) as well as soft skills of software practitioners (*e.g.*, negotiation skills).

This study aims to extend existing work on gaps between industrial needs and software practitioners' education using the Software Engineering Education Knowledge (SEEK) of the SE2014 [3]. Building on top of already-identified shortcomings of SE curriculum models, this work investigates the industrial needs of developers, assesses their satisfaction by the SEEK, and suggests potential directions for improvement. Future SEEK models and the SE education in general could adapt their content according to the findings of this work. Refined curricula could provide future developers with a stronger SE background adapted to the industrial needs, improving their professional careers and absorption.

Insights are provided on the satisfaction of developers' needs, as expressed through Wikipedia articles referenced in Stack Overflow (SO) posts. Wikipedia is frequently used for academic and professional activities, with technologyrelated articles being among the most commonly visited [17], while SO is considered a popular programmer-oriented Q&A forum. According to the 2021 SO developer survey [18], 70% of respondents have at least a Bachelor's degree (or equivalent) and 70% are professional developers. These are mainly occupied in full-stack (50%), back-end (44%), frontend (27%), desktop (17%), mobile development (15%), and DevOps (11%) positions. The majority (63%) have up to ten years of professional coding experience, meaning they have never worked in a world without SO. Moreover, 80% of respondents visit SO weekly, and 55% of them visit daily. As a result, a considerable number of SO users are engaged with SE, with the majority being new in the field. Based on the insights derived from Wikipedia and SO, the needs' satisfaction is assessed through the following research question.

RQ1 To what extent are developers' needs, in terms of Wikipedia articles referenced in SO posts, covered by the SEEK knowledge units?

To examine whether article popularity can indicate less satisfied needs, the relationship between SEEK coverage and Wikipedia article popularity is investigated through the following research question, in terms of citation frequency and votes in SO posts.

RQ2 How does the popularity of Wikipedia articles relate

to their SEEK coverage?

To facilitate future curriculum reports, and limit the gap between industrial needs and education, computing areas underrepresented in the SEEK are listed through the research question:

RQ3 What areas of computing knowledge can be better covered by the SEEK knowledge units?

Finally, qualitative insights about programmers' behavior on SO are provided through the research question:

RQ4 Why are Wikipedia articles covered by the SEEK knowledge units cited on SO?

To validate the study findings, a survey was conducted on SE practitioners. Following published recommendations [19], the code¹ and data (analyzed Wikipedia articles and SO posts, survey questionnaire and responses)² associated with this endeavor are openly available online, and can be used for replication purposes, or to perform further empirical studies.

II. RELATED WORK

The authors of this study consider as related work literature reviews and surveys investigating the gap between SE education and industrial needs, and empirical studies evaluating the role of Wikipedia and SO as learning resources for SE students.

Garousi *et al.* [20] conducted a systematic literature review on the gap between SE education and industrial needs. Topics were classified according to their importance and gap observed in the relevant literature. Many topics were categorized both as *high-importance* and *high-gap*, signifying potential deficiencies in existing curricula. Software requirements, quality, design, testing, and project management are highly important domains, but insufficiently covered by most SE undergraduate programs. Despite the considerable demand for computer fundamentals, little weight is placed by existing curricula, while many programmers feel they have been educated more on engineering foundations and mathematics than on software topics.

The role of Wikipedia as an opportunistic learning resource for prospective software engineers is controversial. While some consider the website useful for students under the right circumstances [21], others disapprove its use for learning new computing concepts, arguing that novice learners should turn to online programmer communities to satisfy their learning needs [22]. However, these communities often lead back to Wikipedia. For instance, Wikipedia references in the August 2012 SO data dump [23] account for about 5% of total references [24], signifying the important contribution of Wikipedia to online programmer communities.

III. METHODS

A. Collection of Wikipedia articles from SO posts

Wikipedia articles referenced in SO posts (questions and answers) were systematically collected from the December

¹https://doi.org/10.5281/zenodo.4251099

²https://doi.org/10.5281/zenodo.5055546

2019 SO data dump.³ The dump contains 18 597 996 questions and 28 248 207 answers posted on the website up to the aforementioned date, along with metadata (*e.g.*, votes). URLs from all Wikipedia language editions (not only the English subdomain) were retrieved through automatic search. Additionally, all different URL formats⁴ and non-clickable references (*e.g.*, in images or text quotes) were taken into account. Each post may also contain multiple references. In total, 474 798 references were retrieved, with 32 332 of them being distinct.

Article titles were isolated from URLs, and their format was canonicalized. Format deficiencies concerned junk characters (*e.g.*, hash signs) and missing punctuation (*e.g.*, closing brackets). Multiple titles might redirect to the same Wikipedia article (*e.g.*, *URL*, *web address*). These titles were resolved through the MediaWiki API⁵ by mapping and renaming them to their redirection article. To assess popularity, titles were complemented with their appearance frequencies and cumulative post scores (*i.e.*, total upvotes minus downvotes).

B. RQ1,2: Mapping of top-referenced Wikipedia articles to the SEEK knowledge units

The most cited Wikipedia articles were manually assigned to the SE2014 SEEK knowledge units, which "provide the foundation for the design, implementation, and delivery of the educational units that make up a SE curriculum" [3]. Thus, SEEK was preferred over a more general computing education guide. In addition, the 2020 ACM/IEEE Computing Curricula report [25], which provides undergraduate curriculum guidelines for the computing education, recognizes the SE2014 as the most suitable and up-to-date guide for the SE discipline.

Five hundred Wikipedia articles, accounting for the top 1% of total references, were manually assigned to the SEEK's 37 knowledge units. This percentage was selected by balancing the need for an adequate article coverage with the available time margin and human resources. In the end, assigned units were aggregated to their general knowledge areas to compute further statistics.

To ensure consistency of this manual process, recommended guidelines suggested in the work of Brereton *et al.* [26] were followed. Two data extraction approaches were combined: the use of two reviewers performing individually the data extraction process and discussing their disagreements; and the use of a data extractor and a data checker.

Following these, the first two authors of this paper individually assessed (in a spreadsheet) the extent of coverage of each Wikipedia article and assigned it to a knowledge unit (if any coverage was noted). The coverage range included the following options: *fully covered*; *partially covered*; *off topic*—the article's topic is not related to any SE field; *general knowledge*; *extremely specialized*; and *not covered*—the topic should be covered but is not (and is also not off topic, general knowledge, or extremely specialized). To amplify human judgment, after observing patterns between articles and knowledge units, a set

of assertions was defined by all authors at the beginning of the procedure, reinforced during the mapping process—these are the following.

- Article topics included in a SEEK knowledge unit's description are fully mapped to it.
- Articles including general information irrelevant to any SEEK unit are off topic.
- Articles on web development and web design are not covered by the SEEK.
- Articles about encoding are extremely specialized, because they are too specific with regard to the SEEK units.
- Articles analyzing fundamental software design patterns are mapped to *Design Strategies* (DES.str), while articles on more advanced pattern implementations are mapped to *Detailed Design* (DES.dd). Articles listing fundamental software design principles are mapped to *Design Con*cepts (DES.con).
- Articles delving into database design are mapped to Detailed Design (DES.dd), while articles about introductory database design concepts are mapped to Computer Science Foundations (CMP.cf).
- Articles on established algorithms are fully mapped to Computer Science Foundations (CMP.cf), while those referring to more specialized algorithms are partially mapped to the same unit.

An example of a not covered article is *ISO-8601*,⁶ involving a widely used international standard for date and time representation that reduces program faults and complexity. Although the topic could be encountered by a software engineer, no SEEK unit appears to cover it. Other not covered article examples are *Cross-origin resource sharing*, *JSONP*, *Ajax (programming)*, *Post/Redirect/Get*, *Comet (programming)*.

A partially covered article is *Android (Operating System)*⁷, involving Android's history, features, hardware, development, security, licensing, and legal issues. Although the topic could be covered by *Operating System Basics* (CMP.cf.9) of *Computer Science Foundations* (CMP.cf), it only provides an introduction without studying the topic adequately, thus it was partially mapped to the unit. Other partially covered articles are *UTF-8*, *Trie*, *Endianness*, *Levenshtein distance*, *JSON*.

Upon completing the assessment, the two authors discussed and partially resolved their disagreements, documenting their opinion. Through this process, 5% of assignments remained conflicting. These were resolved by the paper's last author, again by selecting from all options, drawing on the first two authors' assertions and documented comments as well as his three-decades' experience in SE. In the end, 25% of pending disagreements were resolved in favor of the first author, and 38% in favor of the second. The overall agreement rate between the last and the first two authors was 63%.

C. RQ3: Classification of partially and not covered Wikipedia articles

Wikipedia articles characterized as partially or not covered through the process described in Section III-B were manu-

³https://archive.org/details/stackexchange2019-12-02

⁴https://en.wikipedia.org/wiki/Help:URL

⁵https://www.mediawiki.org/wiki/API:Main_page

⁶https://en.wikipedia.org/wiki/ISO_8601

⁷https://en.wikipedia.org/wiki/Android_(operating_system)

ally classified using the 2012 ACM Computing Classification System (CCS) [27]. The first two authors of this paper together mapped each article by hand to a knowledge area and subarea of the first and second level categories of the system, correspondingly, taking into account the lower level contents of the areas. Again, any reservations that occurred were resolved by the paper's last author.

D. RQ4: Manual coding of SO posts with references to covered Wikipedia articles

To examine why articles covered by the SEEK knowledge units are cited on SO by developers, the first two authors of this paper applied manual coding [28] to a sample of posts referencing covered Wikipedia articles. The sample size of a population of 198 365 posts was calculated at around 384 using Cochran's [29] sample size and correction formula depicted in Eq. 1, which provides a representative sample for proportions of large populations.

$$n_0 = \frac{z^2 pq}{e^2},\tag{1}$$

where n_0 is the required sample size, e the desired margin of error (5%), p the proportion of population (0.5—maximum variability), q = 1 - p, and z is found in the Z table.

Posts were split in two, and each author individually applied codes to a half (in a shared online spreadsheet). The authors read each randomly selected post (question/answer) and produced codes related to the post's content. Posts with similar content and area of question were assigned the same code. At least one and up to five codes were applied to each post. Next, the authors discussed and grouped together conceptually-related codes by generalizing or specializing them. In the end, thirteen aggregated codes (listed in Section IV-D) occurred.

As a result, a post might eventually be associated with more than one general code. For polytomous or continuous variables, Israel [30] in his study on determining sample size suggests using the formula for sample size for the mean, which is similar to Cochran's formula for the proportion (Eq. 1), except for the measure of variability; the formula for the mean employs σ^2 , which is the variance of an attribute in the population, instead of $(p \times q)$. However, using the level of maximum variability (p=0.5) in the calculation of the sample size for the proportion generally produces a more conservative sample size (*i.e.*, a larger one) than the formula for the mean. In this study the level of maximum variability was employed, thus the sample size is considered more conservative than the one that would be calculated by the sample size for the mean.

E. Validation Survey

A survey was conducted on SE practitioners to validate the study findings. Following Kitchenham and Pfleeger's survey guidelines [31], the authors adopted a descriptive survey design by performing a cross-sectional, case control study (*i.e.*, participants were surveyed about their past experiences at a particular fixed point in time), which is typical of surveys in SE. The survey questionnaire consisted of multiple-choice, open-ended, and Likert-scale questions [32]. Documentation

was included about the survey objective and study context, an optional question for comments on the questionnaire, and an option for participants to complete their e-mail address and receive a report with the survey results. The complete questionnaire and responses are included in the dataset (Section I).

To evaluate the questionnaire, a pilot survey was conducted [33] on the members of the authors' laboratory. The questionnaire was improved based on four members' feedback, and the revised version was e-mailed to 23 SE practitioners from eight organizations: Deloitte Greece; Deloitte Poland; Deloitte Spain; SICOA Consulting; Quintessential; GRNET; National Bank of Greece; Workable. The final survey ran from June 23rd to 29th, 2021, and seven responses were received (30% response rate). Four respondents work in software development positions, two are business analysts, and one is a software consultant. Five have graduated from a higher education institution with a SE-related major, one is currently a university student majoring in telecommunications, and one holds a high school diploma. All respondents have been practicing SE as professionals.

IV. RESULTS

A. RQ1: To what extent are developers' needs, in terms of Wikipedia articles referenced in SO posts, covered by the SEEK knowledge units?

The 500 manually analyzed Wikipedia articles (Section III-B) resulted in 306 (61.2%) fully and 88 (17.6%) partially covered, 29 (5.8%) not covered, 13 (2.6%) off-topic, 17 (3.4%) general-knowledge, and 47 (9.4%) extremely specialized cases. Ultimately, 79% of articles discussed on SO are covered by the SEEK.

The coverage of programmers' needs was assessed based on the fully and partially covered Wikipedia articles. The knowledge unit of Computer Science Foundations (CMP.cf), which focuses on the provision of basic SE knowledge, was mapped to the majority (34.6%) of articles. Succeeding units are Detailed Design (DES.dd—8.2%), Mathematical Foundations (FND.mf—7.2%), Construction Technologies (CMP.ct—5.8%), Architectural Design (DES.ar—3.2%), Security Fundamentals (SEC.sfd—3%), Design Strategies (DES.str—2.6%), Construction Tools (CMP.tl—2.2%), Design Concepts (DES.con-2.2%), Problem Analysis and Reporting (VAV.par—1.4%), Computer and Network Security (SEC.net—1.4%), Developing Secure Software (SEC.dev— 1.4%), Engineering Foundations for Software (FND.ef— 1.2%), Human-Computer Interaction Design (DES.hci-1.2%), Software Configuration Management (PRO.cm—1%), Types of Models (MAA.tm—0.6%), Testing (VAV.tst—0.6%), Evolution Process and Activities (PRO.evo—0.6%), Requirements Fundamentals (REQ.rfd—0.2%), Design Evaluation (DES.ev-0.2%).

The remaining units were not mapped to any article. These are Engineering Economics for Software (FND.ec), Group Dynamics and Psychology (PRF.psy), Communication Skills (PRF.com), Professionalism (PRF.pr), Modeling Foundations (MAA.md), Analysis Fundamentals (MAA.af), Eliciting Requirements (REQ.er), Requirements Specification and

Documentation (REQ.rsd), Requirements Validation (REQ.rv), Verification and Validation Terminology and Foundations (VAV.fnd), Reviews and Static Analysis (VAV.rev), Process Concepts (PRO.con), Process Implementation (PRO.imp), Project Planning and Tracking (PRO.pp), Software Quality Concepts Culture (QUA.cc), Process Assurance (QUA.pca), and Product Assurance (QUA.pda).

B. RQ2: How does the popularity of Wikipedia articles relate to their SEEK coverage?

The relation between article popularity and coverage was examined by rating Wikipedia articles according to their frequency in SO posts and the associated posts' cumulative score (Section III-A).

Figure 1 displays for each coverage category the cumulative post voting scores of the corresponding articles. The majority of covered articles are characterized by low-to-moderate popularity, but there is also a noteworthy number of articles that are extremely popular. However, the scores of not covered articles seem to vary widely, ranging from low to high popularity, with only few very popular cases. Extremely specialized articles depict little differences, with a slightly reduced variance, while off-topic and general-knowledge articles mainly display low-to-moderate popularity.

Equivalently, Fig. 2 demonstrates article frequency per category of coverage. Minor differences to Fig. 1 are observed in the distribution of the articles for each category, with general-knowledge articles showcasing noticeably reduced variance. Survey respondents assessed the 20 most cited not covered and partially covered articles as of low importance, aligning with the above observations.

C. RQ3: What areas of computing knowledge can be better covered by the SEEK knowledge units?

Through the process described in Section III-C, Wikipedia articles characterized as partially or not covered were assigned to the 2012 ACM CCS [27] first and second level knowledge areas. Table I presents the frequency of areas and subareas of not covered articles. The majority (55%) fall within the area of *Information systems*, particularly in the subarea of *World Wide Web* (45%), followed by *Computing methodologies* (20%) and *Software and its engineering* (10%).

Table II introduces the knowledge areas of partially covered articles. The majority (49%) correspond to the area of *Software* and its engineering, specifically to the subarea of *Software notations and tools* (43%). Subsequent areas concern *Information systems* (28%) and *Theory of computation* (14%).

To further investigate what areas can be better covered by the SEEK, survey participants assessed the SEEK knowledge units' importance and recommended lecture hours. *Computer Science Foundations* (CMP.cf) and *Testing* (VAV.tst) were rated as the most important SEEK units, while less important units are *Mathematical Foundations* (FND.mf), *Professionalism* (PRF.pr), *Modeling Foundations* (MAA.md), *Software Configuration Management* (PRO.cm), *Evolution Process and Activities* (PRO.evo). The findings indicate that more lecture hours should be devoted to *Security Fundamentals* (SEC.sfd),

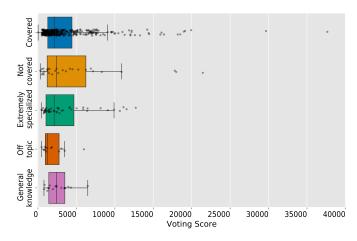


Fig. 1. Article score per category of coverage. Covered, not covered, and extremely specialized articles have similar score distributions, while off-topic and general-knowledge articles are concentrated in the lower score areas.

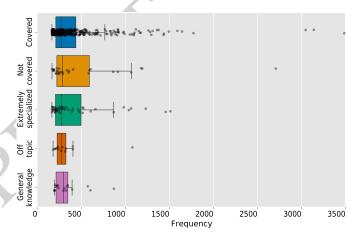


Fig. 2. Article frequency per category of coverage. Off-topic and general-knowledge articles have reduced frequency variance, while the remaining categories' distribution resembles that of Fig. 1.

Computer and Network Security (SEC.net), and Developing Secure Software (SEC.dev)—these all belong to the Security (SEC) knowledge area. In addition, more hours should be allocated to Architectural Design (DES.ar), Design Concepts (DES.con), and Human-Computer Interaction Design (DES.hci). The SEEK could be enriched with problem solving approaches in less technical situations (e.g., efficiently handling setbacks before an app launch), guidelines for high-quality code writing, software life cycle models such as Agile and its methods (e.g., Scrum), as well as individual and professional growth topics (e.g., interview simulations).

Survey participants also assessed a set of topics that were found to be partially or not covered by the SEEK. From these, they consider algorithms as the most important topic, followed by the World Wide Web, specialized software tools and systems (*e.g.*, database management systems), and computer graphics. Respondents suggest that SE curricula should be updated regularly, every one to four years.

TABLE I 2012 ACM CCS [27] AREAS OF NOT COVERED ARTICLES

Area	Subarea	Articles	(%)
Information systems	World Wide Web	13	45
	Information retrieval	2	7
	Data management systems	1	3
Computing methodologies	Computer graphics	4	14
	Parallel computing methodologies	1	3
	Symbolic and algebraic algorithms	1	3
Software and its engineering	Software notations and tools	2	7
	Software creation and management	1	3
Applied computing	Document management and text processing	1	3
General and reference	Cross-computing tools and techniques	1	3
Mathematics of computing	Mathematical analysis	1	3
Networks	Network protocols	1	3

Area	Subarea	Articles	(%)
Software and its engineering	Software notations and tools	38	43
	Software organization and properties	4	5
	Software creation and management	1	1
Information systems	Data management systems	12	14
	World Wide Web	10	- 11
	Information retrieval	3	3
Theory of computation	Design and analysis of algorithms	11	13
	Semantics and reasoning	1	1
Mathematics of computing	Discrete mathematics	1	1
	Mathematical analysis	1	1
	Computer graphics	1	1
Computing methodologies	Artificial intelligence	1	1
	Concurrent computer methodologies	1	1
Security and privacy	Cryptography	2	2
General and reference	Document types	1	1

D. RQ4: Why are Wikipedia articles covered by the SEEK knowledge units cited on SO?

Through the process described in Section III-D a variety of reasons emerged justifying why articles covered by the SEEK knowledge units are cited in SO questions and answers. The aggregated codes assigned to the examined posts were programming language-specific explanation/advice (24%), advice for system/software design (21%), code review/debugging (20%), computer science/programming concept explanation (11%), algorithm recommendation/optimization (9%), tool recommendation (4%), general discussion (3%), exercise help/provide solution (2%), data structure recommendation (2%), testing techniques recommendation (2%), mathematical concept explanation (1%), learning material recommendation (1%), detailed explanation of posted code (1%). One post had been deleted from SO, and was assigned the code N/A.

Survey participants mainly agree with the above reasons.

Furthermore, they use Wikipedia articles to validate their arguments or understand theoretical concepts, while the majority stress that SO can also be used for purposes unrelated to technical issues.

V. DISCUSSION AND IMPLICATIONS

The majority of top-referenced Wikipedia articles concerning SE topics are covered by the SEEK. A striking example is the number of articles mapped to *Computer Science Foundations* (CMP.cf). A reason for the unit's dominance is the wide range of knowledge it embodies and the considerably more lecture hours it requires. The SEEK emphasizes the importance of the foundational computer science concepts, serving as a springboard to more advanced concepts, and this is also validated by survey respondents. The associated need described in Section II seems to be met.

Many articles regarding mathematical topics were observed and mapped to Mathematical Foundations (FND.mf). This contradicts arguments that SE courses should focus less on mathematical concepts. For example, Lethbridge concludes that mathematical topics including calculus, differential equations, and linear algebra have a negative educational gap (i.e., the knowledge learned is greater than their importance), hence less emphasis could be placed on them [10]. However, the manual analysis of posts referencing covered Wikipedia articles (Section IV-D) revealed that few practitioners seek explanations about mathematical concepts, suggesting a lower demand for them. Explanations involve geometry and combinatorics problems applied to specialized programming issues. Mathematical foundations in SE curricula may be sufficient for an average developer, thus it might be worth reducing weight on more advanced concepts to allow space for less covered but highly demanded topics.

Implication 1: The SEEK seems to effectively provide developers with the mathematical foundations they need. Further analysis of SE curricula could indicate whether reducing some weight on more advanced mathematical concepts, releasing space for less covered but highly demanded topics, would have a positive impact on developers.

Survey respondents perceived as extremely important the area of software design. Although various articles were mapped to units of the knowledge area *Software Design* (DES), survey participants recommended allocating more hours to *Architectural Design* (DES.ar), *Design Concepts* (DES.con), and *Human-Computer Interaction Design* (DES.hci). This is reinforced by the fact that one of the most common reasons for citing covered Wikipedia articles in SO posts concerns developers seeking advice for software design and development, such as best implementation practices.

Implication 2: Further investigation could evince the impact of extending the content of the SEEK on practical and specialized approaches related to software design concepts, architectural design, and human-computer interaction design.

Two other equally important areas for practitioners, according to survey participants, are software testing and security. They recommended extending the lecture hours of all units included in the area of *Security* (SEC). Although few Wikipedia articles were related to *Testing* (VAV.tst), possibly because such topics may not be as popular in online programmer communities, still, the incorporation of more testing material in the SEEK could equip students with useful skills for their professional careers.

Implication 3: Further analysis could reflect the value of including more material and allocating more lecture hours to the areas of software testing and security in the SEEK.

Articles only partially covered by the SEEK are associated with specialized software tools and notations, database management systems, and algorithms. Focusing on SE education, the SEEK manages to cover the most relevant articles. However, more specialized programming tools and notations discussed on SO are an exception to the rule, either because they are too specialized to be fully covered by SE education, or they are no longer widely used, hence are nowadays less covered by curriculum models. Additional analysis could indicate whether these gaps should be covered by the SEEK or industrial training.

Additionally, articles related to World Wide Web principles and tools, information retrieval, and computer graphics are less likely to be covered by the SEEK units—the SEEK seems to cover these areas rather superficially. Particularly, the area of computer graphics may be only partially covered because it can be considered less related to SE. Nevertheless, the remaining areas, despite being widely discussed by the community, are barely mentioned in introductory units, revealing potential unsatisfied needs of programmers.

Implication 4: The SEEK could emphasize more information systems, particularly, information retrieval methods, World Wide Web principles and tools, and computer graphics.

The majority of knowledge units not associated with any Wikipedia reference on SO are related to SE concepts with a strong presence of the human factor. These fall within the knowledge areas of *Professional Practice* (PRF), *Requirements Analysis and Specification* (REQ), *Software Process* (PRO), and *Software Quality* (QUA), aligning with the deficiencies outlined in Section II.

In addition, a weak relation was found between article popularity and coverage, regardless of the metric (frequency, voting score) used (Section IV-C). The distribution of both covered and not covered articles is almost identical. The notably reduced number of not covered observations may partially explain the lack of extremely popular not covered articles, compared to the covered ones. Although most articles are covered by the SEEK, the ratio between covered and not covered articles remains unchanged, regardless of their popularity. However, the popularity of off-topic and general-knowledge articles is remarkably lower, especially in terms of

score. Perhaps articles that are either unrelated to computer science, or are considered conventional SE concepts, receive less attention and are rarely mentioned in online programmer communities. However, survey respondents contradict that SO is solely used for technical issues.

Various reasons for citing covered Wikipedia articles on SO were identified during the manual coding process described in Section III-D. Programmers often demand recommendations or explanations regarding SE components such as algorithms and data structures, programming languages, frameworks, testing techniques, and computer science concepts; this highlights the importance for curriculum models to provide deep understanding of computer science and SE fundamentals, aligning with the survey findings. Although programmers typically introduce code snippets to stress their point and provide descriptive examples, there are also many instances where they solely request code review and debugging assistance, as they struggle to detect errors and flaws in their code. Furthermore, developers look for learning material recommendations and tool suggestions to broaden their horizons and expand their professional skills. This demonstrates their willingness to enhance their abilities in the SE field, embracing the idea of autodidacticism. They frequently need assistance in exercises and problems related to their studies or work, revealing a difficulty in applying theoretical knowledge to practice. Finally, developers do not always seek solutions to issues, but aim to initiate general discussions.

VI. THREATS TO VALIDITY

The study's external validity in terms of generalizability suffers by studying the SE2014 SEEK model rather than a real-world curriculum for SE undergraduate studies. However, the SEEK has been thoroughly composed based on input from the SE community through a survey, several workshops and informal discussion sessions, and consists of the essential material for the development of any curriculum in the field [3]. In addition, results mostly target SE education, but could be generalized to other computing fields through study replication using the corresponding ACM curriculum reports.⁸

Threats to the study's internal validity stem from the steps during which manual processes involving subjective judgment were followed: the categorization of Wikipedia articles based on the SEEK knowledge units, the classification of partially and not covered articles using the 2012 ACM CCS, and the manual coding of SO posts. The risk stemming from the latter process is related to the loss of accuracy of the original post due to an increased level of categorization; this threat was reduced by assigning multiple codes to each post. The same process is affected by the restricted number of analyzed posts and the selected sampling technique, which may not be the most appropriate one for the SO population. (For example, SO users must earn reputation points to perform certain acts, while users may exist that interact with large numbers of posts to gain reputation for purposes unrelated to SO.) This limitation could be improved by increasing the sample size in replication studies or by employing different

⁸https://www.acm.org/education/curricula-recommendations

sampling techniques that account for the complexity of the SO population. The trustworthiness of the manual processes was enhanced through the use of multiple raters, and by grounding them on established research methods. However, validity risks derived from manual processes requiring human judgment cannot be completely eliminated [34].

Threats to the internal validity also result from the evaluation of programmers' needs using the SEEK, and the survey process. For the assessment of developers' needs using the SEEK (Section IV-A), all knowledge units were considered equally likely to appear on SO through Wikipedia article references. However, some units associated with fewer references could be less challenging for developers, resulting in fewer posts, thus one should not overinterpret under- or unrepresented SEEK units on SO. Threats stemming from the survey process include the small sample size which prevents generalizability of results, the social desirability bias [35], which may have affected respondents' honesty, and the question-order effect [36], which may have directed participants' answers. To reduce the desirability bias, participants were informed about the anonymity of their responses. Although questions could have been shuffled to avoid the order effect, they were sorted in a convenient manner to assist respondents' comprehension.

VII. CONCLUSION

This study aims to extend existing work on the gap between software practitioners' education and industrial needs by analyzing Wikipedia articles referenced in SO posts. The analysis indicates that common reasons developers reference Wikipedia articles on SO include advice and best practices regarding software design, explanations on computer science concepts, algorithms and data structures as well as code review assistance. Foundational computer science, mathematical, and design concepts preponderate in covered articles, while a noteworthy number of SEEK units related to the human factor found no match. It could be the case that human-related topics are not generally encountered on SO, or the associated SEEK units (i.e., Group Dynamics and Psychology—PRF.psy, Communication Skills—PRF.com, Professionalism—PRF.pr) are not discussed by SO users. In addition, deficiencies were observed in the areas of World Wide Web, computer graphics, and specialized software tools. Weak relation between article popularity (in terms of frequency and post score) and coverage was observed. A survey conducted on software practitioners enhanced and reinforced the analysis findings. It might be worth for future SEEK models and the computing education in general to dive deeper in the areas of information systems, software testing, design, security, and invest more on soft skills, such as teamwork, collaboration, and project management.

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