Mapping A Knowledge Areas of The SWEBOK Standard With The CBOK in Software Engineering Field Using A Set Theory

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***Abstract*—The purpose of this paper is to present a mapping approach for software engineering bodies of knowledge using set theory operations that allows the traceability of mapping and highlights the differences and similarities between the two bodies of knowledge. An example is shown by mapping at the knowledge area level the Guide to the Software Engineering Body of Knowledge (SWEBOK) and the CBOK (Core Body of Knowledge).. The Guide to the SWEBOK, created under the auspices of the IEEE Computer Society, aims to define generally accepted knowledge in software engineering. This paper uses the breakdown of knowledge proposed for the next version of the Guide that is currently under development (V3). In 2009, a group from academia, industry and government published GSwE2009: Curriculum Guidelines for Graduate Degree Programs in Software Engineering. These guidelines also define a core body of knowledge (the CBOK) to be taught in such programs. Further progress will be achieved by mapping the lower levels of detail of these two bodies of knowledge and on analyzing the impact of the identified differences on the software engineering discipline and profession.**

Keywords: Software Engineering Bodies of Knowledge; SWEBOK Guide; GSWE2009; CBOK; Mapping; Set Theory.

I. INTRODUCTION

Software engineering is defined by the IEEE as: "(1) the application of a systematic, disciplined, quantifiable approach to the development, operation and maintenance of software, i.e. the application of engineering to software. (2) The study of approaches as in (1)." [1].

A key milestone in all disciplines is to achieve consensus within the profession on a core body of knowledge, and this has been identified by the IEEE Computer Society as crucial for the evolution of software engineering towards professional status.

To expand on this definition and to develop such an international consensus, the IEEE Computer Society's Professional Practices Committee initiated a project in 1998 and published two versions of the Guide to the Software Engineering Body of Knowledge (SWEBOK), in 2001 and 2004 [2]. Each of the knowledge area descriptions in the SWEBOK Guide was developed by domain experts and has gone through a number of review cycles and consensus-building steps within the international community of peers. Version 3 of the SWEBOK Guide (V3) is currently under development.

The Graduate Software Engineering 2009 (GSwE2009) - Curriculum Guidelines for Graduate Degree Programs in Software Engineering [3], provides guidelines for professional or course-based Master's degree programs in software engineering. These guideline were developed by representatives from academia, industry, government, and professional societies and are now under the stewardship of the IEEE Computer Society and the ACM. The core content of these curriculum guidelines is known as the CBOK, or Core Body of Knowledge. The SWEBOK Guide was used as a primary source for the development of the CBOK, but a number of changes were made to meet the specific requirements of GSWE2009.

This paper investigates the differences between the published baseline breakdown of topics of the SWEBOK Guide V3 and that of the CBOK. Set theory is used to perform the mapping between the two breakdowns of topics. Unlike manual mapping approaches, the proposed approach is systematic and rigorous.

The analysis of such differences can improve the content of each body of knowledge as well as improving curricula and course material based on these bodies of knowledge. The analysis of such differences can also enable a better understanding of minor differences or even different school of thought regarding how software engineering is understood as a discipline and practiced as a profession.

The paper is organized as follows: Section 2 reviews the literature. Section 3 describes the mapping between the SWEBOK Guide and the CBOK at the knowledge area level. Section 4 presents an analysis and a discussion. Section 5 presents a brief conclusion, including future work.

II. LITERATURE REVIEW

This section describes the two related inputs to this paper: the SWEBOK Guide and the CBOK, incorporated within GSWE2009. Set theory operations are also briefly documented in this section.

A. Guide to the Software Engineering Body of Knowledge (SWEBOK)

The Guide to the Software Engineering Body of Knowledge (SWEBOK Guide) has been developed with the following objectives:

- To characterize the content of the software engineering discipline;

- To promote a consistent view of software engineering worldwide;
- To provide a topical access to the software engineering body of knowledge;
- To clarify the place, and set the boundary, of software engineering with respect to other disciplines;
- To provide a foundation for curriculum development and individual certification material.

The 2004 Version of the SWEBOK Guide is also recognized as an ISO/IEC Technical Report [4]. Version 3 (V3) of the SWEBOK Guide is currently under development and is not yet available. However, the baseline breakdown of topics of V3 has been published (available at www.swebok.org), and contains 15 Knowledge Areas (KAs). Among these, eleven characterize the practice of software engineering: software requirements, software design, software construction, software testing, software maintenance, software configuration management, software engineering management, software engineering process, software engineering methods, software quality, and software engineering professional practice. A further four KAs characterize the educational requirements of software engineering: engineering economy foundations, computing foundations, mathematical foundations, and engineering foundations.

B. *Core Body of Knoweldge (CBOK)*

In 2007, various stakeholders from academia, industry, government, and professional societies joined together to develop curriculum guidelines for graduate degree programs in software engineering within a project named the Integrated Software and Systems Engineering Curriculum (iSSEc).

The first product of the iSSEc project is Graduate Software Engineering 2009 (GSWE2009) - Curriculum Guidelines for Graduate Degree Programs in Software Engineering..The primary goal of GSwE2009 is to provide guidelines for the development of professional or primarily course-based Master‘s degree programs in software engineering.

These guidelines identify the core body of knowledge (CBOK) to be taught to graduate students in Master’s degree programs. The CBOK therefore constitutes the core of the curriculum, and is hierarchies in three levels: knowledge area, subarea, and topic, subtopic. It is composed of the following knowledge areas: ethics and professional conduct, system engineering, requirements engineering, software design, software construction, testing, software maintenance, configuration management, software engineering management, software engineering process, and software quality.

The CBOK also includes three knowledge areas introduced as preparatory knowledge: mathematics fundamentals, computing fundamentals, and software engineering. GSwE2009 builds on the Software Engineering Institute (SEI) curriculum [5], in addition to the Guide of Software Engineering Body of Knowledge (SWEBOK) and Software Engineering 2004: Curriculum Guidelines for Undergraduate Degree Programs in Software Engineering (SE2004) [6].

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C. *Related Work using Manual Mapping Approaches*

To date in the software engineering literature, mapping between software engineering bodies of knowledge or from a body of knowledge to other artefacts is performed manually, which can lead to errors and omissions and a lack of traceability. For example, [7] presents a manual mapping between two bodies of knowledge: the version of the SWEBOK Guide published in 2001 and the Software Engineering Education Body of Knowledge (SEEK) incorporated into a earlier version of [6]. As well, manual mappings have been performed between the SWEBOK Guide KAs and existing expertise from various universities in [8], between a set of competencies and their associated evidences and SWEBOK Guide KAs in [9], and between the SWEBOK Guide breakdown of topics at varying levels of granularity and graduate degree programs or syllabuses in software engineering in [10-12].

D. *Basic Operations of Set Theory*

Set theory is a fundamental theory in mathematics, and is the branch of mathematics that studies sets. A set is composed of a collection of objects, concepts, and vocabularies. Many operations can be performed on sets, the basic ones being union, intersection, and difference. Using the list of knowledge areas in each body of knowledge as sets, the three basic set operations can be defined as follows:

The set of knowledge areas = $\{e|e \in S \vee e \in C\}$ (1)

$$S \cup C = \{e|e \in S \vee e \in C\} \quad (2)$$

$$S \cap C = \{e|e \in S \wedge e \in C\} \quad (3)$$

$$S - C = \{e|e \in S \wedge e \notin C\} \quad (4)$$

Where:

- The knowledge areas are represented by element (e);
- The list of KAs in the SWEBOK Guide is a set represented by (S), and the list of knowledge areas in the CBOK is a second set represented by (C);
- The symbols ($\vee$, $\wedge$) mean *or* and respectively;
- The symbols ($\in, \notin$) mean that the element *belongs to* and *does not belong to* respectively.
- The symbols ($\cup, \cap, -$) mean *union*, *intersection*, and *difference* respectively.

III. Proposed Mapping Approach

The SWEBOK Guide and the CBOK are both composed of knowledge areas. Each knowledge area is decomposed into hierarchical levels: subareas, topics, and subtopics – see Figure 1. The mapping approach presented in this paper can be performed at any level: knowledge area, subarea, topic, and subtopic, using the two-phase approach shown in Figure 2.

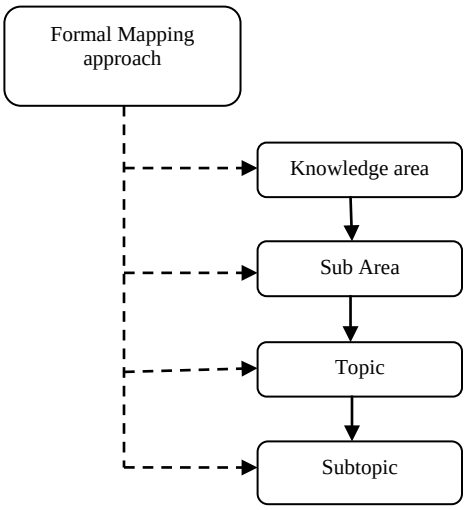

Figure 1. Mapping Levels

This approach is composed of two phases:

- The initiation phase consists of defining the two sets that will be the object of the mapping. In this example, they are the list of knowledge areas in the SWEBOK Guide and in the CBOK. Secondly, each element of each set is assigned a symbol. In this case, each knowledge area of each body of knowledge area is assigned a distinct symbol.
- The application phase consists of applying the three set operations defined above to the two sets that have now been established: union, intersection, and difference.

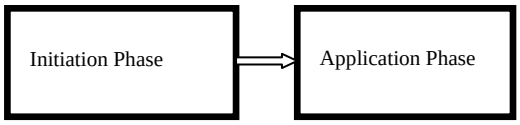

Figure 2. Mapping using an approach based on Set Theory

IV. Mapping Between the SWEBOK Guide and the CBOK

This section applies the proposed approach to the list of knowledge areas in each body of knowledge.

A. *Initiation Phase*

The set of KAs in the SWEBOK Guide consists of the following:

(S) = {Software requirements (SR), Software design (SD), Software construction (SC), Software testing (ST), Software maintenance (SM), Software configuration management (SCM), Software engineering management (SEM), Software engineering process (SEP), Software engineering methods (SEME), Software quality (SQ), Software engineering professional practice (SEPP), Engineering economy foundations (EEF), Computing foundations (CM), Mathematical foundations (MF), Engineering foundations (EF)}

Or

$$S = \{SR, SD, SC, ST, SM, SCM, SEM, SEP, SEME, SQ, SEPP, I$$

The set of knowledge areas in the CBOK consists of the following:

CBOK (C) = {Ethics and professional conduct (EPC), System engineering (SYE), Requirements engineering (RE), Software design (SD), Software construction (SC), Testing (T), Software maintenance (SM), Configuration management (CM), Software engineering management (SEM), Software engineering process (SEP), Software quality (SQ), Computing fundamentals (CF), Mathematics fundamentals (MF), Software engineering (SE)}

Or

$$C = \{EPC, SYE, RE, SD, T, SM, CM, SEM, SEP, SQ, MF, CF, SE\}$$

B. *Application Phase*

Union of the SWEBOK Guide and the CBOK

$$S = \{SR, SD, SC, ST, SM, SCM, SEM, SEP, SEME, SQ, SEPP, I$$

$$\cup$$

$$C = \{EPC, SYE, RE, SD, T, SM, CM, SEM, SEP, SQ, MF, CF, SE\}$$

For this union operation, the naming of the SWEBOK Guide KAs is adopted. For instance, the name 'Software Requirements' as used in the SWEBOK Guide is adopted, rather than 'Requirements Engineering' as used in the CBOK, and 'Software Testing' is adopted instead of 'Testing'.

The set below is the result of the union operation between the SWEBOK Guide (S) and the CBOK (C):

{SR,SD,SC ST,SM,SCM,SEM,SEP,SEME,SQ,SEPP,SYE, EF,EEF,CF,MF,SE}

The first column in Table 1 lists the SWEBOK Guide KAs, the second column lists the CBOK KAs, and the third column contains the result of the union operation, meaning the KAs that are present in the SWEBOK or in the CBOK.

Table 1: SWEBOK Guide and CBOK union, and intersection results

SWEBOK Guide	CBOK	SWEBOK ∪ CBOK	SWEBOK ∩ CBOK
Software requirements (SR)	Requirements engineering (RE)	Software requirements	Software requirements
Software design (SD)	Software design (SD)	Software design	Software design
Software construction (SC)	Software construction (SC)	Software construction	Software construction
Software testing (ST)	Testing (T)	Software testing	Software testing
Software maintenance (SM)	Software maintenance (SM)	Software maintenance	Software maintenance
Software configuration management (SCM)	Configuration management (CM)	Software configuration management	Software configuration management
Software engineering management (SEM)	Software engineering management (SEM)	Software engineering management	Software engineering management
Software engineering process (SEP)	Software engineering process (SEP)	Software engineering process	Software engineering process
Software engineering methods (SEME)		Software engineering methods	
Software quality (SQ)	Software quality (SQ)	Software quality	Software quality
Software engineering professional practice (SEPP)	Ethics and professional conduct (EPC)	Software engineering professional practice	Software engineering professional practice
Engineering economy foundations (EEF)		Engineering economy foundations	
Computing foundations (CF)	Computing fundamentals (CF)	Computing foundations	Computing foundations
Mathematical foundations (MF)	Mathematics fundamentals (MF)	Mathematical foundations	Mathematical foundations
Engineering foundations (EF)		Engineering foundations	
	System engineering (SYE)	System engineering	
	Software engineering (SE)	Software engineering	

SWEBOK Guide and CBOK Intersection

S ∩C:

$$S = \{SR, SD, SC, ST, SM, SCM, SEM, SEP, SEME, SQ, SEPP, \}$$

∩

$$C = \{EPC, SYE, RE, SD, T, SM, CM, SEM, SEP, SQ, MF, CF, SE\}$$

The set below is the result of the intersection operation performed between the SWEBOK Guide (S) and the CBOK (C):
{SR, SD, SC, ST, SM, SCM, SEM, SEP, SQ, SEPP, CF, MF}

The fourth column in Table 1 shows the KAs that are present in both the SWEBOK Guide and the CBOK.

SWEBOK Guide and CBOK Difference

The difference operation uses the following equation to illustrate the knowledge areas that are included in the SWEBOK Guide, but not in the CBOK:

:

$$S = \{SR, SD, SC, ST, SM, SCM, SEM, SEP, SEME, SQ, SEPP, \}$$

-

$$C = \{EPC, SYE, RE, SD, T, SM, CM, SEM, SEP, SQ, MF, CF, SE\}$$

The knowledge areas that are included in S and not in C are: {SEME, EEF,EF}

$C - S$: The knowledge areas that are included in C, but not in S: {SYE, SE}

Table 2 describes, from left to right, the SWEBOK Guide KAs, the CBOK knowledge areas, the knowledge areas that are present in the SWEBOK Guide, but not in the CBOK, and the knowledge areas that are present in the CBOK, but not in the SWEBOK Guide. Knowledge areas that are present in both bodies of knowledge are not shown in Table 2.

TABLE II. SWEBOK Guide and CBOK difference results

SWEBOK GUIDE	CBOK	SWEBOK GUIDE – CBOK (S-C)	CBOK – SWEBOK GUIDE (C-S)
Software engineering methods (SEME)		Software engineering methods	
Engineering economy foundations (EEF)		Engineering economy foundations	
Engineering foundations (EF)		Engineering foundations	
	System engineering (SYE)		System engineering
	Software engineering (SE)		Software engineering

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V. Results Analysis and Discussion

The mapping of the SWEBOK Guide to the CBOK using basic set theory operations at the knowledge area level showed the following results:

- A total of 17 knowledge areas are included either in the SWEBOK Guide or in the CBOK or both, as shown using the union operation. Of these, 15 are present only in the SWEBOK Guide and 13 are present only in the CBOK.
- A total of 12 knowledge areas are included in both the SWEBOK Guide and in the CBOK, as shown using the intersection operation.
- A total of 3 knowledge areas included in the SWEBOK Guide are not included in the CBOK, as shown using the difference operation, and two KAs included in the CBOK are not included in the SWEBOK Guide.

This mapping showed the following differences regarding the KAs characterizing the practice of software engineering in the SWEBOK Guide and the core knowledge areas of the CBOK:

- The naming of the following KAs: software requirements, software testing, software configuration management, and software engineering professional practice, as adopted in the SWEBOK Guide, is changed in the same order to: requirements engineering, testing, configuration management, and ethics and professional conduct.
- The software engineering methods KA is included in the SWEBOK Guide, but not in the CBOK.
- The system engineering knowledge area is included in the CBOK, but not in the SWEBOK.

The differences related to the educational requirements of software engineering in the SWEBOK Guide and the preparatory knowledge areas in the CBOK are the following:

- Engineering foundations is included in the SWEBOK Guide, but not in the CBOK.
- Computing fundamentals and mathematical fundamentals in the CBOK are considered as preparatory knowledge areas. In the SWEBOK Guide, they are considered as educational requirements of software engineering, with slightly different names: computing foundations and mathematical foundations.
- The software engineering knowledge area is included as a preparatory knowledge area of the CBOK. It defines the basic knowledge that students should possess in software engineering when entering a Master's degree program. This knowledge area is not included in the SWEBOK Guide.

The differences related to both the core knowledge areas in the CBOK and the educational requirements of software engineering in the SWEBOK Guide are the following:

- Engineering economics is considered an educational requirements KA of software engineering in the SWEBOK Guide but is not covered in the CBOK at least not at the knowledge area level.

VI. Conclusion and Future Work

This paper investigates the differences between the published baseline breakdown of topics of the SWEBOK Guide V3 and the CBOK using a mapping approach based on set theory operations. This mapping was performed at the level of the knowledge area. Future work will concentrate on mapping more in-depth levels of the SWEBOK Guide to the CBOK, and on analyzing these results. These results will enable a better understanding of how different communities view the the discipline and profession of software engineering. Automated tools to support this approach are also being considered.

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