Software Measurement Body of Knowledge – Initial Validation using Vincenti's Classification of Engineering Knowledge types

Alain Abran, Luigi Buglione, Asma Sellami

École de Technologie Supérieure - ETS

1100 Notre-Dame Ouest,

Montréal, Canada H3C 1K3

aabran@ele.etsmtl.ca, Luigi.Buglione@computer.org, asma.sellami.1@ens.etsmtl.ca

Abstract:

The Guide to the SWEBOK (2001 Trial version) currently contains ten distinct software engineering Knowledge Areas (KAs) and three common themes: Quality, Tools and Measurement. The Measurement topic is pervasive throughout all the KAs (in both the 2001 and 2004 editions). An initial taxonomy for a new specific KA on Software Measurement had been proposed in 2003. To improve this initial proposal, the Vincenti classification of engineering knowledge types was used as an analytical tool. This paper presents a revised breakdown for a body of knowledge on Software Measurement.

Keywords

SWEBOK, Software Measurement, Knowledge Area, Vincenti's classification, Engineering Knowledge, ISO TR 19759.

1 Introduction

One of the key projects specifically designed to contribute to the recognition of Software Engineering as a *bona fide* engineering discipline is the *Guide to the Software Engineering Body of Knowledge* (SWEBOK). This project has been sponsored by the IEEE Computer Society [4] and supported by a consortium of industrial sponsors. The main goal of the SWEBOK was to develop an international consensus on the "generally accepted knowledge" in the Software Engineering domain. The relevance of the SWEBOK has been recently enhanced by its acceptance as an ISO technical report (ISO/IEC 19759:2004) [11]. This Guide to the SWEBOK was developed in a three-phase approach:

1st release: *Straw Man* version – 1997,

2nd release: *Stone Man* version (also referred to as the Trial Version – 2001 [1],

3rd release: *Iron Man* version – 2004 [3] (freely available on the SWEBOK website at: www.swebok.org)

The Guide to the SWEBOK documents the consensus on the structure of the relevant software engineering knowledge, which consists of ten (10) Knowledge Areas (KAs): the first five KAs represent what the ISO calls the *primary* processes in the 12207 standard [8], and the other five KAs the *support* and *organizational* processes (see Table 1). The KAs have a common architecture, as illustrated in Fig. 1.

SWEBOK Knowledge Areas (KAs)	**ISO 12207 Process types**
1. Software Requirements	Primary processes
2. Software Design	
3. Software Construction	
4. Software Testing	
5. Software Maintenance	
6. Software Configuration	Support and organizational processes
7. Software Engineering Management	
8. Software Engineering Process	
9. Software Engineering Tools & Methods	
10. Software Quality	

Table 1: Guide to the SWEBOK: KAs [3]

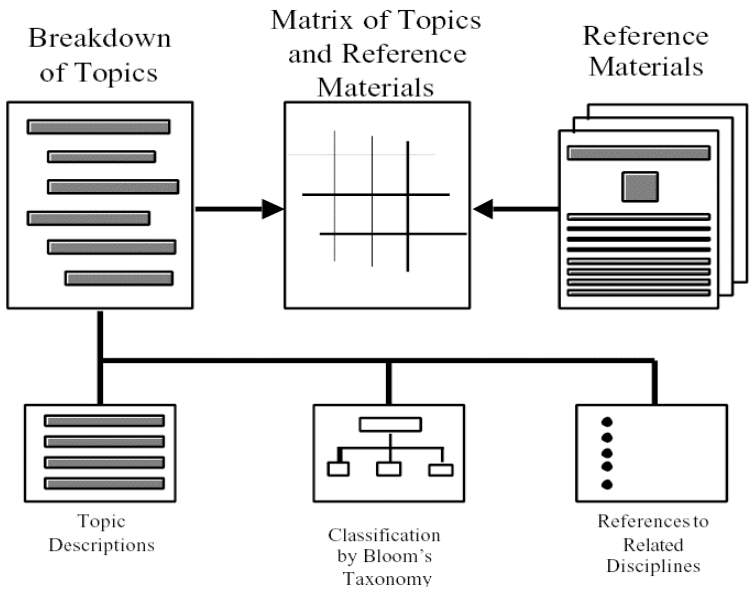

Figure 1: Organization of a KA description in the SWEBOK [3]

In the Guide to the SWEBOK, there are also some *common themes*, cutting across most KAs, such as *Quality*, *Tools* and *Measurement.* Two of these have been recognized as distinct KAs in themselves, that is, Quality and Tools. Measurement, however, did not make it as a distinct KA. In this paper we explore reasons why the measurement theme has not been recognized as a KA, and we propose contributions that hopefully will lead to the recognition of software measurement a KA in its own right.

Measurement is, of course, fundamental to the engineering disciplines and, on these grounds, it had been given to the all the KA associate editors as a criterion for identifying relevant generally accepted knowledge in their respective KAs. In the event, distinct associate editors initially developed each of the 10 KAs individually, which led to different levels of breadth and depth of treatment of a subtopic such as measurement. Furthermore, measurement-related knowledge has not been developed equally across KAs over the recent history of software engineering.

An initial, unified view of the measurement knowledge in software engineering was proposed in [6] in the form of a distinct KA on Software Measurement, taking into account all the measurement-related items from the existing KAs in the 2001 edition of the Guide to the SWEBOK and organizing them into an initial breakdown.

In 2003-2004, Guide to the SWEBOK went through its *Iron Man* revision. Various contributors have added measurement-related knowledge, including in some KAs where treatment of measurement had initially been fairly weak, such as in the Construction KA. Within this review cycle, a specific proposal for the addition of a new KA had been proposed by two of the international reviewers, but these proposals were not accepted on the basis that measurement had not yet become generally accepted in the software engineering community, and that no detailed structure had yet been validated by the community of peers in the software engineering measurement community.

This paper presents a revision of this measurement BOK using both the 2004 version of the SWEBOK, as well as an analysis of measurement knowledge using the Vincenti classification of engineering knowledge types.

The paper is organized as follows: Section 2 presents the software measurement topics included in the Guide to the SWEBOK (2001 and 2004 versions) and our initial proposal for a new KA on Software Measurement. Section 3 illustrates an analysis of such a breakdown using the Vincenti classification of engineering knowledge. Section 4 presents the revised breakdown. Finally, section 5 presents some conclusions and suggestions for further research.

2 Related Work

2.1 Schneidewind BOK

Schneidewind [14] proposed an initial version of a body of knowledge (BOK) for software quality measurement because it is considered important to engineers to produce high-quality software. This proposal of a BOK contains a set of nine measurement-related issues – Table 2.

Id.	Measurement Issues
1	Measurement goals
2	Costs and risks
3	Context
4	Operational profile
5	Models
6	Data requirements
7	Measurement types and granularity
8	Product and process test and evaluation
9	Product and process quality prediction

Table 2: Schneidewind Quality Measurement BOK [14]

2.2 An initial proposal for a Software Measurement KA

Another attempt to develop a taxonomy and structure for a KA on software measurement was proposed in [6] on the basis of the 2001 version of the Guide to the SWEBOK and is presented in Figure 2. This initial proposal was based on the identification of measurement-related topics in the Guide to the SWEBOK, a synthesis of the various elements listed and the authors' view of an appropriate taxonomy.

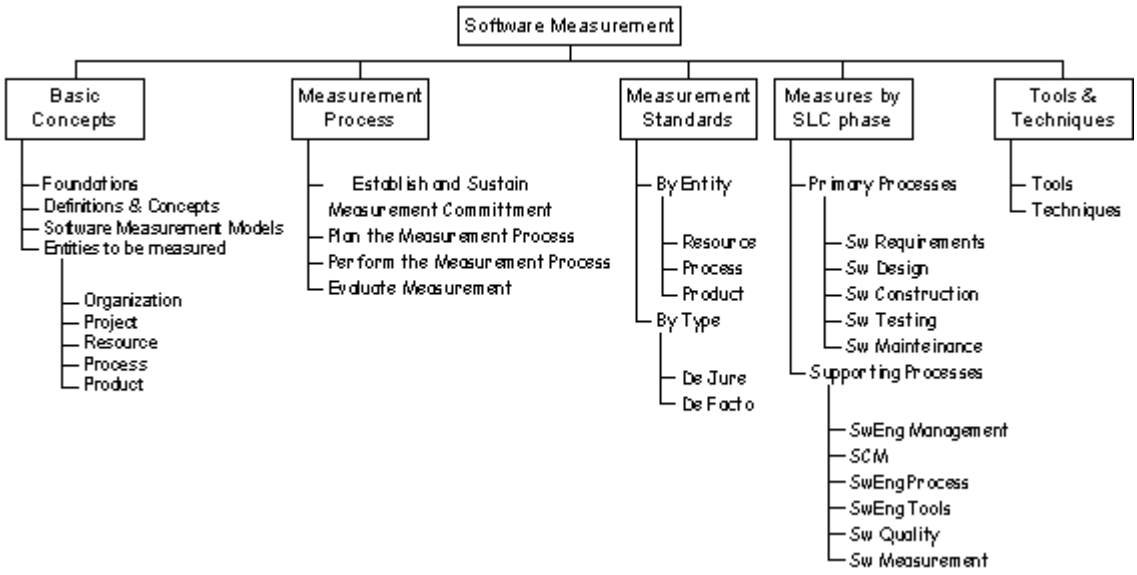

Figure 2: Initial proposal of a Taxonomy for a Software Measurement KA – SWEBOK 2001 [6]

2.3 Comparison

While the BOK proposed by [14] consists of a sequential list of issues (9) on software quality measurement, the initial taxonomy proposed in [6] is more generic and structured. An initial mapping between the two BOKs can only be tentative due to the different basis for structuring – Table 3. For instance, Issue 1 (*Goals*), deals with entities to be measured. Issue 2 (*Costs and risks*) and Issue 3 (*Context*) handle some elements of basic concepts and some discussion about measures by SLC phase. Issue 4 (*Operational profile*) and Issue 5 (*Models*) deal with the application of measurement process and some elements of basic concepts. Issue 6 (*Data requirements*) covers elements of measurement process. Issue 7 (*Measurement type and granularity*) deals with foundations in basic concepts and measurement process. Issue 8 (*Product and process test and evaluation*) deals with measurement process and measurement by SLC phase and Issue 9 (*Product and process quality prediction*) also covers some elements of measurement process and tools and techniques.

Table 3 lists, for each of Schneidewind's measurement issues, which measurement-related concepts in the proposed taxonomy of a software measurement KA [6] are identified. This highlights, for example, that the topic of measurement standards is not identified in [14].

Measurement Taxonomy / Schneidewind Issues	Basic concepts	Measurement process	Measurement standards	Measure by SLC phase	Tools & Techniques
Issue 1: *Goals*	Entities to be measured				
Issue 2: *Cost and risk*	Software measurement models			Primary processes Supporting process	
Issue 3: *Context*	Entities to be measured			Supporting process	
Issue 4: *Operational profile*	Entities to be measured	Establish and sustain measurement commitment Plan the measurement process Perform the measurement process Evaluate measurement			
Issue 5: *Models*	Software measurement models Entities to be measured	(Idem to issue 4)			
Issue 6: *Data requirements*		(Idem to issue 4)			
Issue 7: *Measurement types and granularity*	Foundations	(Idem to issue 4)			
Issue 8: *Product and process test and evaluation*		(Idem to issue 4)		Primary processes Supporting process	
Issue 9: *Product and process quality prediction*		(Idem to issue 4)			Tools

Table 3: Mapping of Schneidewind measurement issues to the proposed software measurement taxonomy

2.4 SWEBOK 2004 inputs

The new 2004 version of the SWEBOK has been revisited and the measurement-related topics have been identified. Table 4 presents a summary of the measurement-related issues treated in the SWEBOK 2004, by KA and by corresponding level in its taxonomy. The main changes to measurement issues in the 2004 version are:

- **KA.01 (SwRequirements)** – Measuring requirements is now a new 2nd-level topic, with an emphasis on functional size measurement (FSM).
- **KA.03 (SwConstruction)** – while in the 2001 edition, this was the only KA with no explicit reference to measurement, measurement is now addressed in the subsection for construction quantitative measures.
- **KA.07 (SwEngineering Management)** – this KA has been redesigned with a major measurement section aligned with ISO/IEC 15939:2002 [10], and focusing more on the process side of measurement.

	Measurement knowledge areas	1st-level topic	2nd-level topic	3rd-level topic	What
1	**Software Requirements**	02. Requirements Process	04. Process quality & improvement	---	Req.Eng. coverage by SPI standards & models Req.Eng. measures & benchmarking Improvement planning & implementation
		07. Practical Considerations	05. Measuring Requirements	---	Sizing Requirements using an FSMM
2	**Software design**	04. SW Design Analysis & Evaluation	03. Measures	--- ---	Function-oriented design measures OO design measures
3	**Software construction**	02. Managing Construction	03. Construction Measurement	---	Quantitative measures
4	**Software testing**	04. Test-related Measures	01. Evaluation of the Program Under Test	---	Quantitative measures
			02. Evaluation of the Tests performed	---	Quantitative measures
		05. Test Process	01. Practical Considerations	06. Cost-effort estimation and other process measures	Quantitative measures for managing the process
5	**Software maintenance**	02. Key issues in Software Maintenance	04. SW Maintenance Measurement	01. Specific measures	Quantitative measures
6	**Software configuration management**	01. Management of the SCM process	05. Surveillance of SCM	01. SCM Measures and Measurement	Quantitative measures
7	**Software engineering management**	06. Software Engineering Measurement	01. Establish and Sustain Measurement Commitment	---	BSC concept; establishing h/l relationships among measures for management
			02. Plan the Measurement Process	---	GQM approach; measurement validity; Model building, calibration and evaluation; implementation, interpretation and refinement of models; Survey techniques and form design; automated and manual data collection

			03. Perform the Measurement Process	---	
			04. Evaluate Measurement	---	Measures on the Measurement process for continuous improvement
8	**Software engineering process**	03. Process Assessment	02. Process Assessment Methods	---	CBA-IPI; SCAMPI
		04. Process & Product Measurement	01. Process Measurement	---	Process outcomes (FPs, LOCs, FP/PPM, …)
			02. Software Product Measurement	01. Size measurement	FSMM units
				02. Structure measurement	Quantitative measures about control-data flow and module structure and interaction
				03. Quality measurement	ISO/IEC 9126:2001 parts 1-4
			03. Quality of Measurement Results	---	Theory of measurement; ISO Vocabulary on Metrology
			05. Process Measurement techniques	01. Analytic techniques	QIP, Process simulation, Orthogonal Defect classification, SPC, PSP
				02. Benchmarking techniques	SW-CMM, SPICE, ISO 9001, Trillium, Bootstrap, …
9	**Software engineering tools and methods**	01. Software tools	07. Software Engineering Management tools	---	Measurement tools are just mentioned as one of the three categories of tools
10	**Software quality**	03. Practical Considerations	04. Software Quality Measurement	---	Product & SQM Process Measures; analysis techniques; defect analysis

Table 4: Measurement-related items in the SWEBOK 2004

- **KA.08 (SwEngineering Process)** – this KA was redesigned introducing several changes. In particular, the size-structure-quality measurement issues, previously in the KA.07, are now within the new "Software product measurement" sub-issue, focussing – in the case of size – on the usage of an FSM method (citing the ISO/IEC 14143-1:1998 [9]) standard and – in the case of quality – on the new ISO 9126 four-part standard, previously part of the KA.10 (SwQuality). A new Process Assessment section was also introduced.
- **KA.10 (SwQuality)** – with the integration of many measurement-related topics into the redesign of KA.07 and KA.08, the Quality KA now includes only a software quality measurement subissue in the Practical Considerations section.

While the 2004 edition provides more precise references to measurement and re-structures the positioning of measurement within the topics discussed in many KAs, no key elements were added that were not already present. In summary, this revision has completed the coverage of measurement within SWEBOK, but is not adding new measurement within the BOK already proposed in [6].

3 Evaluation

This section discusses the evaluation of the proposed BOK. To analyze the initial breakdown for a Software Measurement KA from an engineering viewpoint, the classification of engineering knowledge types by Vincenti [15] was chosen. Vincenti, on the basis of his analysis of the evolution of aerospace engineering knowledge, identified different types of engineering knowledge, and classified them into six categories (Table 5), including, of course, quantitative data as a category of engineering knowledge.

Vincenti postulated that this classification was not specific to aerospace engineering, but more generic and applicable to engineering in the broad sense. Software being significantly different from other physical artifacts, there had not yet been any attempt to apply general engineering principles to software. It had nevertheless been suggested to the KA specialists that they use this classification for their initial draft of each KA of the SWEBOK; this was, of course, a challenging assignment: in the late ’90s, the software engineering domain was not mature enough and the classification could not be directly implemented in most of the KA taxonomy and description.

Of interest here is not the entire software engineering domain, but only in a subset of it, that is, the mapping of software measurement knowledge to the categories of engineering knowledge types. For instance, while the *design* concept is considered generically in Vincenti’s classification, it can be transposed to the relevant elements within each of the 10 KAs which all include corresponding processes (requirements process, design process and testing processes, all of which require a design of some sort to tackle the generalities and peculiarities of any project); similar tailoring is required for other topics such as the measurement topic.

To apply the Vincenti classification, it is preferable to have criteria for classifying each subtopic within each category, a list of such criteria having been identified in [13]. The more refined tailoring of the measurement terms and concepts is presented in the right-hand column of Table 5. For instance, in the context of this specific analysis about measurement, *design* can refer to the design of a specific measure, to the design for combining various measurement components into aggregated measures or to the design of related measurement models for the utilization of measurement results, such as in quality models, productivity models and estimation models.

#	Vincenti's Categories	Abbr.	Criteria in [13]	Tailoring to Measurement Concepts
1.	**Fundamental design concepts**	**FD**	a) Operational principles b) How its characteristic parts fulfil their special functions in combining to an overall operation which achieves the purpose	c) Measurement principles d) Set of metrology concepts (see [7])
2.	**Criteria and specifications**	**CS**	e) Specific requirements (of operational principles) f) Limits (across an entire technology)	g) Characteristics of measuring instruments (see [7])
3.	**Theoretical tools**	**TT**	h) Concepts about 'design' i) Intellectual tools for thinking about 'design'	j) Measurement theory k) Measure process model
4.	**Quantitative data**	**QD**	l) Represented in tables and graphs	m) Measurement references n) Codified experimental data
5.	**Practical considerations**	**PC**	o) Theory often not sufficient – considerations from experience and practice p) Trade-offs which are the result of general knowledge about the device, its use and context	q) Experimental approaches and related strengths and weaknesses
6.	**Design instrumentalities**	**DI**	r) Knowing how – ways of thinking s) Procedural knowledge	t) Measurement procedures u) Measurement analysis techniques v) Measurement – lessons learned

Table 5: Vincenti's classification of engineering knowledge – and related criteria

In this analysis, Vincenti's classification is used to recognize and identify the types of engineering knowledge included in the software measurement KA. Table 6 presents an initial mapping of the 2nd-level topics of the proposed measurement BOK into Vincenti's classification of engineering knowledge types. A study of the content of this mapping provides some insights into the current strengths, and weaknesses, of software measurement as engineering concepts and related tools.

Knowledge Topics	Fundamental Design concepts	Criteria and Specifications	Theoretical Tools	Quantitative Data[1]	Practical Consideration	Design Instrumentali-ties
Basic concepts						
Foundations	X					
Definitions & concepts	X					
Design of software measures			X			
Entities to be measured		X	X			
Models for the use of measurement results			X		X	X
Evaluation			X		X	X
Comparison – benchmarking			X		X	X
Estimation – planning			X		X	X
Measurement process	X					
Establish and sustain measurement commitment	X				X	
Plan the measurement process	X				X	
Perform the measurement process	X				X	
Evaluate measurement	X				X	
Measurement standards		X				
By entity		X				X
By type		X				X
Measure by SLC phase		X				
Primary processes		X				
Organizational & supporting processes		X				
Tools & techniques						
Measuring instruments					X	X
Measurement analysis techniques					X	X
Model analysis techniques					X	X

Table 6: Preliminary classification of BOK measurement concepts and Vincenti

A consolidation of the measurement topics and subtopics within each of the categories of engineering knowledge is presented next in Table 7.

[1] Not included directly in the SWEBOK, but might be included in the references.

#	Vincenti's Categories	Abbr.	Measurement BOK – Topics	Measurement BOK – Subtopics
1.	Fundamental design concepts	**FD**	Basic concepts	Foundations Definitions & concepts ISO standard on measurement process (ISO 15939)
2.	Criteria and specifications	**CS**	Basic concepts	Entities to be measured
			Measure by SLC phase	Primary processes Organizational & supporting processes
3.	Theoretical tools	**TT**	Basic concepts	Design of software measures Entities to be measured Models for the use of measurement results
4.	Quantitative data	**QD**		*(Not included directly in the SWEBOK, but might be included in the references)*
5.	Practical considerations	**PC**	Basic concepts	Models for the use of measurement results
			Measurement process	Establish and sustain measurement commitment (Guidelines) Plan the measurement process (Guidelines) Perform the measurement process (Guidelines) Evaluate measurement (Guidelines)
			Tools and techniques	Measuring Instruments Measurement analysis techniques Models analysis techniques
6.	Design instrumentalities	**DI**	Basic concepts	Models for the use of measurement results
			Measurement standards	Measurement standards by entity Measurement standards by type
			Tools & techniques	Measuring Instruments Measurement analysis techniques Models analysis techniques

Table 7: Preliminary summary of Vincenti & BOK measurement topics

This analysis has allowed us to identify where further research on software measurement, from an engineering perspective, is required. Thus, some improvement points from an engineering perspective can be identified:

- The proposal in [6] of a BOK for Software Measurement covers five of six of Vincenti's categories, with the exception of the Quantitative Data area (cf. Footnote 1). In other disciplines of engineering, measurement method and measuring instruments have long been established and must satisfy the full set of metrology concepts of the VIM [7], including quality criteria about measurement results, such as accuracy, repeatability and reproducibility. This highlights the lack of measurement references in software engineering.

- Measurement design methods, as well as measuring instruments and experimentally validated models of evaluation and estimation, are not as mature in the Software Engineering domain. What is needed is a more precise definition of software measurement, and one which is based on verifiable approaches. The application of metrology concepts to software measurement may contribute to the improvement of measurement methods and measurement-related instruments, and therefore to the improvement of the BOK for measurement.

Therefore, an updated proposal for a BOK for Software Measurement is proposed in the next figure, including an additional leaf on the right.

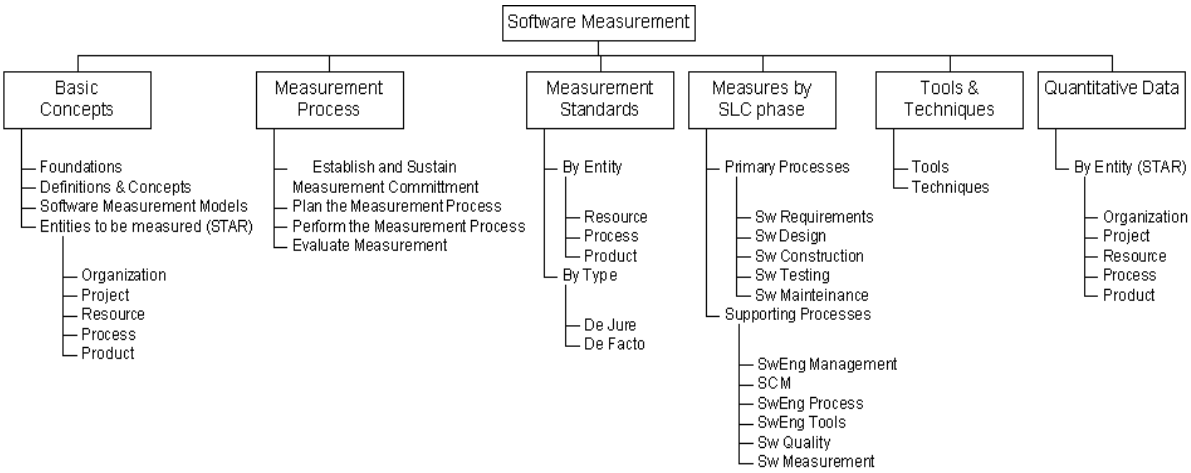

Figure 3: Update of a Taxonomy for a Software Measurement Body of Knowledge

This updated version is subdivided into five subleafs, using the STAR [4] entity taxonomy, where the criterion for inserting "generally accepted" references about Quantitative Data will be chosen on the strengths of the experimental validation methods used to derive them, in particular by the "observational" category, because of their direct impact on projects at a low cost, for instance *project monitoring* and *field studies*, according to the classification by Zelkowitz & Wallace [16].

Some short examples: in the *process* subleaf, a possible reference to include would be the CBA-IPI/SCAMPI biannual reports by the Software Engineering Institute[2], while in the *product* subleaf it will be possible to include studies about FSM measurement experiences validated by the COSMIC group (if they are related to the COSMIC-FFP Measurement Method), and so on [12].

[2] Available from the SEMA webpage : http://www.sei.cmu.edu/cmmi/appraisals/appraisals.html#appraisal-results

4 Summary and discussion

Interest in Software Measurement is increasing in the Software Engineering community, and much related knowledge has been included in the Guide to the Software Engineering Body of Knowledge (SWEBOK), even though measurement issues are distributed among the 10 KAs composing the BOK and not initially recognized to be a KA in its own right. In terms of investigating whether or not Software Measurement is a mature enough discipline to have its own space in a future revision of the SWEBOK, a proposal for a new KA has already been made in a previous work [6], illustrating the rationale for such a proposal.

With a view to improving on this proposal, two different checks were performed:

- A comparison with a previous study on a BOK for Software Quality Measurement [14] revealed the relevance of international standards as fundamental for covering the "generally accepted" criterion and updating the initial proposal breakdown for a new SWEBOK KA on Software Measurement.
- The usage of the Vincenti classification of engineering knowledge types as an analytical tool to study the initial proposal breakdown. After updating and aligning the initial proposal to the SWEBOK 2004 *Iron Man* version, it was found that all the criteria were covered (even though not all at the same level), with the exception of Quantitative Data (QD).

Following performance of these checks, a new improved breakdown has been proposed, with the criterion to be followed for choosing and inserting "generally accepted" references for the new Quantitative Data leaf.

The next step toward a complete and validated proposal for a new KA for Software Measurement will be given by the verification of the level of experimental support for each topic in the new KA proposal, according to the Zelkowitz & Wallace taxonomy of validation methods [16].

References

1. ABRAN A., MOORE J.W., BOURQUE P., DUPUIS R., TRIPP L., *Guide to the Software Engineering Body of Knowledge – Trial Version*, IEEE Computer Society, Los Alamos, 2001, URL: http://www.swebok.org
2. ABRAN A., SELLAMI A. & SURYN W., *Metrology, Measurement and Measures in Software Engineering*, Proceedings of the 9th IEEE International Software Measures Symposium (MEASURES'03), 3-5 September, 2003, Sydney, Australia, pp.1530-1545, URL: http://www.lrgl.uqam.ca/publications/pdf/798.pdf

3. ABRAN A., MOORE J.W., BOURQUE P., DUPUIS R. & TRIPP L., *Guide to the Software Engineering Body of Knowledge – 2004 Version*, IEEE Computer Society, Los Alamos, 2004, URL: http://www.swebok.org

4. BOURQUE, P., DUPUIS, R., ABRAN, A., MOORE, J.W., & TRIPP, L.L., *The Guide to the Software Engineering Body of Knowledge*, IEEE Software, Vol. 16 No.6, November/December 1999, pp. 35-44, URL: http://www.lrgl.uqam.ca/publications/pdf/463.pdf

5. BUGLIONE L. & ABRAN A., *ICEBERG: a different look at Software Project Management*, IWSM2002 in "Software Measurement and Estimation", Proceedings of the 12th International Workshop on Software Measurement (IWSM2002), 7-9 October 2002, Magdeburg (Germany), Shaker Verlag, ISBN 3-8322-0765-1, pp. 153-167

6. BUGLIONE L. & ABRAN A., *The Software Measurement Body of Knowledge*, Proceedings of 1st Software Measurement European Forum (SMEF2004), January 28-30, 2004, Rome (Italy), ISBN 88-86674-33-3, pp.84-94

7. ISO, *International Vocabulary of Basic and General Terms in Metrology*, International Organization for Standardization – ISO, Geneva, 1993, pp. 49

8. ISO/IEC JTC1/SC7/WG7 N72, *International Standard 12207 – Information Technology: Software Life Cycle Processes*, 22/02/95

9. ISO/IEC, *IS 14143-1:1998 – Information technology -- Software measurement -- Functional size measurement -- Part 1: Definition of concepts*, Geneva, International Organization for Standardization, 1998

10. ISO/IEC, *IS 15939:2002– Software Engineering -- Software measurement process*, Geneva, International Organization for Standardization, 2002

11. ISO/IEC, *ISO/IEC FDTR 19759: Software Engineering -- Guide to the Software Engineering Body of Knowledge – SWEBOK*, Final Draft Technical Report, N3035, International Organization for Standardization - ISO, Geneva, 8 May, 2004

12. KHELIFI A., ABRAN A. & BUGLIONE L., *A System of References for Software Measurement with ISO 19761 (COSMIC-FFP)*, 14th International Workshop on Software Measurement (IWSM2004), 3-5 November, 2004, Berlin (Germany)

13. ROBERT F., ABRAN A. & BOURQUE P., *A Technical Review of the Software Construction Knowledge Area in the SWEBOK Guide*, 10th International Workshop on Software Technology and Engineering Practice (STEP2002), October 06 - 08, 2002, Montréal, Québec, Canada, URL: http://www.lrgl.uqam.ca/publications/pdf/761.pdf

14. SCHNEIDEWIND, N.F., *Body of Knowledge for Software Quality Measurement*, IEEE Transactions on Software Engineering, Vol. 35 No.2, February 2002, pp. 77-83, URL: http://csdl.computer.org/comp/mags/co/2002/02/r2077abs.htm

15. VINCENTI G.W., *What Engineers Know and How They Know It – Analytical Studies from Aeronautical History*, Johns Hopkins University Press, 1990, ISBN 0801845882

16. ZELKOWITZ M.V. & WALLACE D.R., *Experimental Models for validating Technology*, IEEE Computer, May 1998, pp. 23-31, URL: http://www2.umassd.edu/SWPI/science/r5023.pdf