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Using GSwE2009 for the Evaluation of a Master Degree in Software Engineering in the Universidad de la República

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***Abstract*—This paper presents an adoption and adaptation of the Curriculum Guidelines for Graduate Degree Programs in Software Engineering (GSwE2009) proposed by the IEEE-CS and the ACM for the creation of a curriculum for a Master's degree in software engineering at the Universidad de la República (Uruguay). A method for evaluating contents and its application is also presented. This evaluation allows us to know the obtained thematic coverage, effort and balance. It also provides information that enables the detection of numerous opportunities for the improvement in the implementation of the program.**

I. Introduction

The complexity and functionality of software systems, as well as their criticality, grow every year. Due to all this, it is necessary for software to be developed correctly and efficiently.

Software Engineering (SE) consists in the application of systematic, disciplined and quantifiable approaches to the development and maintenance of the software [1]. Software professionals (software engineers) must apply professional practices in order to be able to produce quality software, meeting the needs of the users in time and within the set budget [2].

The growth and strengthening of a profession (mainly of the professionals who practise it) is closely related to the education in the discipline of said profession [3]. Education in SE should be different from the education in computer science because their objectives as disciplines are different [4], [5]. From that perspective the IEEE-CS and the ACM propose guidelines for the construction of curricula (undergraduate and graduate) for 5 different computing related disciplines. [2].The curricular guide SE2004 is the proposal for undergraduate degrees in SE [6] and the curricular guide GSwE2009 is the one for graduate degrees [7], [8]. These guides are reference curricula, in other words, they serve as reference to create curricula adapted to a specific context.

The GSwE2009 reference curricula (from now on we will use "*the GSwE2009*" to refer in short form to the reference curricula GSwE2009) is a curriculum guideline for master's degree programs on software engineering. It can be used as a guide for those universities which are designing or improving their professional Master's degree programs on software engineering [8]. A professional Master's Degree is intended for people who are primarily interested in pursuing a career in the practice of SE (as opposed to an Academic Master's Degree). Although in the GSwE2009 it is explained that it has not been developed to certify graduate programs, it is clearly stated what is necessary for a graduate program to satisfy the guide.

At the Universidad de la República (UdelaR) located in Uruguay, we develop the curriculum for a Master's Degree in SE based on the GSwE2009. In this article, first we present the use of the guideline for the construction of the curriculum showing the adaptations we had to make considering our context. Then we present how this curriculum was implemented during the years 2012 and 2013. Finally, we made a comparative evaluation with GSwE2009 based on the contents offered during 2012 and 2013. This comparison gives us the opportunity to make changes to the curriculum and its implementation, which ends up generating a continuous improvement in our program.

The rest of the article is divided into the following sections. The section II presents the GSwE2009. The section III presents the use of GSwE2009 in the UdelaR. The section IV presents the method for the comparison of the contents. The results of the comparison are presented in the section V. The related work is presented in the section VI. The section VII presents the conclusion and future work.

II. GSwE2009

GSwE2009 is a curriculum guideline for graduate degree programs in software engineering and is used as a reference curriculum. The evolution and maintenance of the GSwE2009 curriculum are managed by the ACM and the IEEE-CS. In this section we briefly present the central aspects of the GSw2E2009: the architecture, the core body of knowledge (CBOK), the expected outcomes when a student graduates from a master's program and the expected student background when entering the master's program.

A. GSwE2009 Architecture

The architecture of the GSwE2009 includes the: preparatory material, core material, University specific materials, elective materials and a capstone experience.

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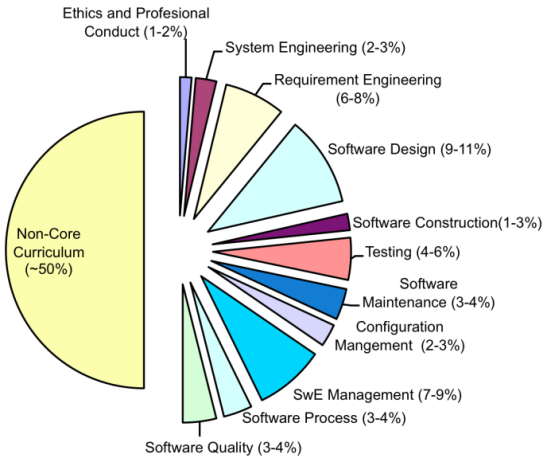

Fig. 1. Distribution of effort in percentage. Source: GSwE2009 [8]

The preparatory material specifies the knowledge that the students should possess when entering a master's program.

GSwE2009 identifies the fundamental skills and knowledge that all graduates of a master's program in SE must possess. These define the core body of knowledge (CBOK).

The University specific material represents materials that an institution might include in order to tailor its program to meet its specific objectives.

The elective content makes it possible for the students to focus on their own interests within the approach set by the program.

The GSwE2009 recommends that students demonstrate their accumulated skills and knowledge in a capstone experience, which might be a project, a practicum, or a thesis. The capstone experience would likely be between 3 to 6 American credits.

B. Core Body of Knowledge (CBOK)

The CBOK is a description of the main abilities, knowledge and experience the students are expected to acquire in order to achieve the expected outcomes once they finish the degree. The CBOK was developed mainly from the SWEBOK 2004 [9].

The CBOK is organized hierarchically in three levels. The first level is the knowledge areas (KA). Each knowledge area is divided into units and each unit in topics. At unit level (second level) the depth of knowledge the students are expected to acquire in approximately 200 contact hours is indicated (less than 50% of the total of credits) expressed in Bloom's Taxonomy [10].

The CBOK contains 11 KA. At KA level the effort distribution is defined (time used by the student) in percentage form. These percentages must be used as a guide and not as a precise specification of a curriculum. Figure 1 presents them.

C. Expected outcomes when the student graduates

The GSwE2009 curriculum establishes 10 expected outcomes when the student graduates. In the Table I the 10 outcomes are presented, together with a brief description of each of them.

D. Expected background when entering the Master's program

GSwE2009 recommends that the programs should have between 33 and 36 American credits. This represents a total workload of between 1287 and 2016 hours[1]. It is expected that a full time student should be able to finish the program in a period between 18 to 24 months.

GSwE2009 assumes that entering students meet all of the following requirements:

- They have completed an undergraduate degree in computing, engineering or in an area of science with some study in computing.
- They have completed an introductory course in software engineering.
- They have at least two years practical experience on some aspect of software engineering.

III. Curriculum based on GSwE2009 at the UdelaR

The Universidad de la República (UdelaR) is the biggest of all Uruguayan universities and the only state University.

The informatics undergraduate degree of the UdelaR belongs to the School of Engineering. This degree has similarities with the *Curriculums Guidelines for Undergraduate Degree Programs of Computer Science* [11] and *Software Engineering* [6]. The estimated duration of this program is 5 years.

The degree programs, both undergraduate and graduate at the UdelaR, are defined in two levels: Curriculum and Implementation of the Curriculum. The Curriculum has among its main components the definition of knowledge areas (Subjects) and the minimum credits that are necessary in each Subject in order to graduate. The credit measures the overall estimated effort an average student must make to complete a course successfully. A credit is the equivalent of 15 total work hours dedicated by the student. These hours include: class attendance, individual study, laboratory time and any other effort the student makes to take and finish the course successfully. The Curriculum also defines the minimum number of credits the student must get to complete the degree (the sum of the minimum credits per Subject might be lower than the total required).

The Implementation of the curriculum is a set of restrictions on the Curriculum. To put it simply, the Implementation can be understood as the definition of a group of compulsory courses the students must take in order to complete the degree and a set of elective courses. Each course awards credits in one or more Subjects of the Curriculum.

[1]An American credit is the equivalent of 13 or 14 contact hours plus homework. Homework hours are the equivalent of two or three class hours. The total workload of the GSwE2009 in credits goes from 33 credits (minimum) to 36 credits (maximum). In order to calculate the minimum number of hours the minimum GSwE2009 is used (33 credits) and the least number of hours per credit: 13 classroom hours plus twice as many hours devoted to individual work. This equals 1287 hours (13+13x2)x33. Using 36 credits and the maximum workload per credit you reach 2016 hours.

TABLE I
DESCRIPTION OF THE EXPECTED OUTCOMES FOR GRADUATES

Resultado	Descripción
CBOK	Master the CBOK. The CBOK specifies Bloom levels that should be achieved for each KA.
Domain	Master software engineering in one application domain and in one application type.
Depth	Master at least one KA or sub-area from the CBOK to the Bloom Synthesis level.
Ethics	Be able to make ethical professional decisions and practise ethical professional behavior.
Sys. Eng.	Understand the relationship between software engineering and systems engineering and be able to apply systems engineering principles and practices in software engineering.
Team	Be an effective member of a team, capable of leading an area of software development or maintenance.
Reconcile	Be able to reconcile conflicting project objectives, finding acceptable compromises within limitations of cost and time.
Perspective	Understand and appreciate the feasibility analysis, the negotiation and good communications with the stakeholders.
Learn	Be able to learn new models, techniques and technologies when they emerge. Appreciate the need for continuous professional development.
Tech	Be able to analyze current software technologies, compare them to alternative technologies and specify and promote improvements or extensions to those technologies.

A. Curriculum for the MSE

During the first semester of 2011 we built a Curriculum based on GSwE2009 for a Master's Degree in Software Engineering (MSE). In this section we present a description of the adaptation made to suit the main points presented in GSwE2009 to our University's reality.

Architecture of the Curriculum of the MSE

We defined the Architecture of the Curriculum in such a way that the Subjects (knowledge areas of a Curriculum of the UdelaR) coincide with the 11 KA of the CBOK. The GSwE2009 aims at covering these 11 KA. Although the Curriculum we developed does not require minimum credits for each Subject, students must have at least one credit in at least 6 Subjects.

The total number of credits required (in courses) by the MSE is 70. It is the equivalent to 1.050 student's effort hours.

The curriculum of the MSE also includes a master's thesis which is worth 40 credits which demands a 600 hour effort on the part of the student.

Our University's Software Engineering Research Group ("*Grupo de Ingeniería de Software*", referred to as GrIS below) has a low number of professors in the team. It is currently composed of 12 professors only two of whom have full time commitment to the University.

The same as the GSwE2009, the aim of our curriculum is that the graduate be able to master the fundamental areas of SE.

Expected Outcomes When a Student Graduates from the MSE-UdelaR

The proposed Curriculum aims at achieving 9 out of the 10 expected outcomes proposed by GSwE2009 curriculum. The outcome that is not included in the curriculum is the Domain (mastering software engineering in a particular domain and type of application).

The GrIS does not focus on the study of SE for a particular application domain. This implies that the courses taught in the MSE will be generic as far as the application domain is concerned. It is for this reason that the students who graduate from the MSE will not achieve depth in an application domain (as established in the outcome Domain of GSwE2009).

Our perception and knowledge of the local and South American situation is that it is common for professionals working in the field of information technology and particularly those who are software engineers, to change jobs regularly. This makes it necessary for those professionals to learn new application domains. It does not seem reasonable in this context to develop a graduate degree in which a specific application domain should be developed in depth, but the contrary. This is the other reason why it was decided to prioritize a greater depth in the CBOK rather than achieve the Domain outcome.

Requirements to enter the MSE-UdelaR

The requirements to enter the MSE only indicate that the students should have an undergraduate degree in informatics of at least 360 credits (4-year undergraduate degrees according to UdelaR's standards). Consequently, the entrance requirements are less than those demanded by the GSwE2009.

However, it is important to point out that in Uruguay's current reality most of the students enter the labor market in the years prior to getting their undergraduate degree. Besides, it is expected that most of the student who enter the Master's Degree Program have completed the informatics undergraduate degree at UdelaR.

This undergraduate degree has 450 credits (5 years) and has two mandatory courses related to software engineering: Introduction to Software Engineering and Software Engineering Project.

The course Introduction to Software Engineering is a 10-credit course. Its aim is to provide an overview of the most relevant aspects of software engineering.

The Software Engineering Project is a 15-credit course. Its aim is to strengthen and deepen the knowledge of software engineering, contrast them with their practical application and integrate them with learning objectives from other courses. In this course projects are conducted with groups of 10 to 15 students for a real customer (locally established companies). In order to do this, a process similar to the Rational Unified process [12] in which each of the students plays one or more specific roles is followed [13].

These two courses compensate, in a way, for the expected student background when entering the Master's Degree program suggested in GSwE2009. Evaluating the previous

preparatory knowledge suggested by GSwE2009 we observe that all the KA proposed are considered in the compulsory courses of our undergraduate degree program. However, at the moment we have not set the Bloom level in each one as the GSwE2009 does.

Capstone experience MSE-UdelaR

GSwE2009 includes a capstone experience that can be a thesis, a project, or practical work. It can be done individually or in a team.

Our University demands that all master's degree programs should end with a thesis done individually. Within this frame, individual projects are admitted as long as the final product is a thesis.

By writing the final thesis the student is expected to deepen his knowledge on a specific knowledge area; contributing strongly to complying with the Depth outcome set forth in GSwE2009.

UdelaR's MSE total workload

As previously mentioned, GSwE2009 estimates that master's degree programs have a total workload of between 1287 and 2016 hours. The total expected workload of the MSE is 1650 hours, therefore it is within the range estimated by GSwE2009. It is divided into 1050 hours devoted to courses and 600 hours for the final thesis. The 600 thesis hours are approximately twice the expected hourly load of the final capstone experience proposed by GSwE2009.

B. Implementation of the MSE Curriculum

The first Implementation of the MSE Curriculum was developed at the end of 2011. The first generation of students of the MSE started its courses in April 2012. This generation finished its studies towards the end of 2013.

The aim of the Implementation is to have at least one course for every KA of the GSwE2009 despite the current limitations of the GrIS. Some of the graduate courses were taught some years ago within the frame of another master's degree program and other courses were created especially for the MSE. Some professors of the GrIS were assigned for the courses designed especially for the MSE to certain topical areas and they were given freedom to design courses in that area. These two situations involving the courses (existing courses and new courses with academic freedom) are one of the reasons why a comparative evaluation of contents with those of GSwE2009 is made.

The suggested set of courses for the first generation of students during 2012 and 2013 and the real total hours of each of them are presented in the Table II. The total number of real hours was registered by one of the authors who took each one of the courses as a student. The names of the courses give an idea of the type of subject-matter each one tackles. The complete description of the courses can be found in http://www.fing.edu.uy/cpap/cursos.

TABLE II
COURSES AND TOTAL NUMBER OF HOURS

Name of the Course	Total Hrs
Soft. Eng. Development Practices - Requirements	21,50
Soft. Eng. Development Practices - Software Design	21,00
Soft. Eng. Development Practices - Construction	14,00
Soft. Eng. Development Practices - Testing	21,00
Software Architecture	145,00
Software Engineering Costs	77,50
Configuration Management	60,00
Modeling and Simulation of Business Processes	69,50
Introduction to the CMMI-DEV	44,00
Software Inspection: the Inspection Process	71,00
Estimation of Soft. Development and Maintenance Projects	39,00
Testing in the Software Development Process	113,75
Software Maintenance	70,25
Software Construction	57,00
Software Project Management	102,25
Introduction to the CMMI-ACQ	42,50

IV. METHOD FOR COVERAGE EVALUATION

The evaluation of the thematic coverage of a curricula compared to a guide or standard is no trivial issue. Several decisions must be taken when defining the method for such evaluation and those decisions will determine certain limitations in the results. For example, the evaluation could be based on the curriculum and the number of credits awarded for each course, interviews with the professors, interviews with the students, external experts, etc. Any of the above may end up having some influence on the results and limiting the conclusions.

A. Thematic coverage measured in hours

The aim of our evaluation is to know how the CBOK is covered thematically in the MSE. Knowing what is covered thematically can be seen as a list of themes of the CBOK (KA, units and/or topics) in which the coverage measure is binary: a certain theme is either covered or it is not. However, knowing how it is covered thematically is very different.

In this article we define "how it is thematically covered" as the knowledge of which themes are covered and how many hours a student devotes to each theme considering all the courses of the MSE. For this reason, we choose not to use the syllabus of each subject where the estimated number of hours required by each course is specified. In order to get more precise information about the number of hours devoted to the course we prefer to take into account the real number of hours a student takes to do a course. The hours considered are both contact hours (hours in class with a professor) and non-contact hours (hours out of the classroom).

Knowing the dedication in hours gives us a clear idea of which are the themes taught during each of the courses and how much time (measured in hours) is devoted to each theme. Then, this results of dedication (thematic coverage) could be contrasted, for example, with results obtained from tests performed to the students in order to know if they are actually learning what it is expected, and what levels of knowledge are being achieved (for example the Bloom level achieved).

Having information about the real hours dedicated in each theme is also important because it allows to know what is actually being taught in each course. It also gives information of which themes are covered by the program and which are not. Therefore, knowing the dedication in hours could be seen as a first step in the process of continuous improvement of an implementation of a curriculum.

For the coverage evaluation we divide the hours of dedication of the student during the courses into:

Theoretical contact hours – They correspond to the classroom time devoted to the presentation of theoretical material by the course lecturers or by the students.

Practice and laboratory contact hours – They correspond to the classroom time devoted to the presentation and/or solution of practical exercises or laboratory. Practical work includes conducting application exercises associated with the theory presented in the theoretical presentation, as well as reading and analyzing articles indicated by the professor. Work in the lab makes it possible to focus on the experimentation of techniques and methods described in the theoretical courses.

Practice and laboratory non-contact hours – They correspond to the time out of the classroom devoted to the solution of practical exercises or labs.

Evaluation hours – They correspond to the time devoted to conducting tests that make possible the evaluation of the knowledge acquired by the students within the frame of a course.

Study hours. They correspond to the hours employed by the student to study individually or in group apart from the rest of the defined hours. This is the only case of estimated hours, not real hours. The reason why these hours are estimated is that they vary a lot from one student to another. In order to make the most of each course it is understood that the students should study one hour for every theoretical contact hour. In other words, the value of study hours is the same as the value of theoretical contact hours.

Therefore, the total number of hours devoted by a student to a certain theme is calculated as the sum of the different types of hours used on such theme.

Contact hours are divided into themes as the course progresses. For the non-contact hours one of the authors took each of the courses as a student and used his real dedication as an estimation of the real average dedication of the rest of the students. The hours dedicated by one student were considered instead of the ones estimated by the professors, since it is a complex issue for the professors to estimate exactly how much time is going to be devoted to each one of the themes related to a non-contact assignment.

This way of measuring non-contact hours has its limitations. However, within the frame of the MSE it was difficult or almost impossible to ask each of the students to keep a record of the effort made. Taking into account this weakness, the professors in charge of each course were asked whether they agreed with the number of hours recorded by the student or if it would be convenient to adjust them for them to better reflect the time the professor considers that on average those tasks should take.

We don't have quantified how much the non-contact hours variate between different students. However, the total number of hours considered (real hours) generally match the expected workload effort of each course; so we might think that the measures taken are quite reliable. As future work, in order to improve how the non-contact hours are measured, more students could keep a record of their effort. In that case, we must take into account that it will be more difficult to manage and that it is not easy to find students that are willing to do this extra work.

Taking into account the total number of hours (contact and non-contact) has the advantage that it allows us to have a more global outlook of the thematic coverage in terms of hours of the MSE. However, non-contact hours are not exact so they must be taken only as an estimate.

B. Method for assigning hours per topic

The thematic coverage of the CBOK is done by assigning the hours described per topic. The topic is the most granular unit of the CBOK and from the information collected at this level, simply summarizing, it is possible to obtain the same information at unit level or at KA. This is done for every course that makes the MSE. Therefore, at the end, the hours are assigned at topic, unit and KA level of the CBOK for all the MSE.

The method for assigning hours per topic involves three steps: assigning hours per topic for the course, reviewing it with the professor and finally processing the data in order to evaluate the obtained coverage. The first two steps are taken for each one of the courses of the MSE and the last step is performed only once after the hours for all the courses have been assigned. This is presented in Fig. 2.

The first step when assigning hours per topic is performed by one of the authors of this article in his role of student of each course. For each course, the number of hours (specifying type of hours) devoted to each theme is recorded in an electronic spreadsheet. Then all the topics of the CBOK of GSwE2009 are analyzed and the hours of each theme of the course are assigned to the corresponding topics of the CBOK (again specifying type of hour). The study hours are assigned and distributed in the same way as the theoretical contact hours were.

For most of the given courses it has been decided not to assign to topics the evaluation hours. This is due to the fact that in general in the evaluations items of many topics are covered, and if a division by topics were attempted, the proportional division of hours per topic would be insignificant. However,

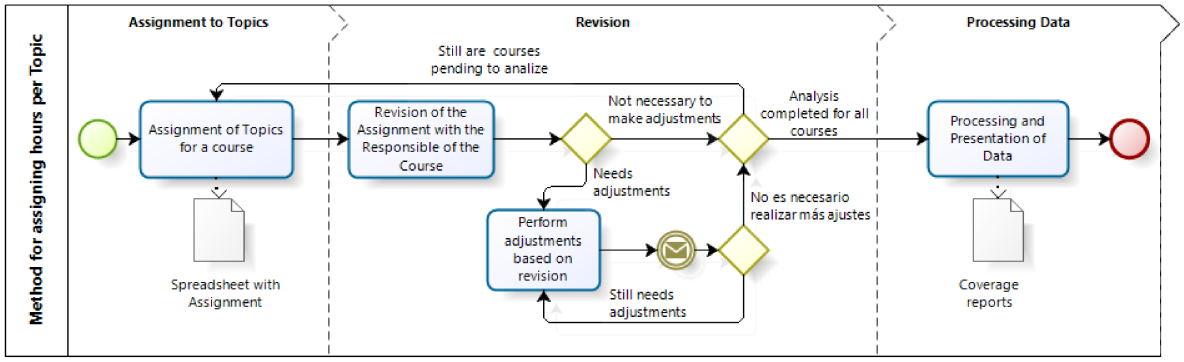

Fig. 2. Steps of the method for assigning hours per topic

for those courses that are closely associated with a KA in particular (in which the vast majority of the topics included belong to a KA) it is decided to assign the evaluation hours to the KA in question (without associating unit or topic). At the same time, in the implementation of the plan there are some (few) courses in which most of the content of the course is associated with a particular topic of the CBOK. For these courses, like for example "Software inspection: the inspection process" the decision has been taken to assign the evaluation hours at topic level.

Once the distribution of hours per topic of a course has been completed, a review with the professor in charge of the course is done (second step of the method). In order to do this, a meeting with the professor is held, where he is informed of the work done and then the association of the themes of the course with topics of the CBOK and the corresponding hour distribution are reviewed. Furthermore, if the course has practice or non-contact lab work, the professor is presented with the number of hours recorded for those tasks. Should there be diversion in the non-contact hours considered in connection with the estimated hours in the curriculum for this purpose, there is a negotiation with the professor as to whether it is convenient to leave the real hours (for instance, when it is known that the assignment proposed took more hours than those indicated in the syllabus) or if the hours stated in the curriculum should be considered (for example when an assignment was done with more depth and effort (hours) than expected). Once the meeting is over, the necessary adjustments in assigning topics for the course are made. If during the review it is decided that many changes have to be made, the electronic spreadsheet is sent via e-mail to the professor so that he can check whether the changes have been implemented according to his comments. The aim of this phase is to validate the way the hours have been assigned in the first phase and try to guarantee that assigning items to topics and the distribution of hours to them is a faithful representation of reality.

Finally, the third step of the method is performed once the hours have been assigned to topics for all courses. This step involves processing all the collected data in a single pre-formatted electronic spreadsheet. This electronic template enables us to provide support for obtaining the different metrics related to the coverage obtained in the different levels of abstraction of the CBOK.

V. Result of the Comparison of Thematic Contents of the MSE with GSwE2009

In this section we present some of the results obtained in our evaluation work of the MSE. We present the results of thematic coverage, thematic effort and thematic balance achieved in the MSE compared to the GSwE2009.

A. Thematic Coverage

Next we present the thematic coverage of the topics of the GSwE2009 showing which of these themes are considered in the MSE courses. This gives us an outlook at KA, unit and topic level of which themes have been addressed and which have not.

Figure 3 presents the coverage obtained at KA, topic and unit level for the KA, "Ethics and Professional Conduct". This type of information allows us to know which KA, units and/or topic are not covered or are well covered by the Implementation of the Curriculum (concerning the GSwE2009). The topics colored in green are covered by some course of the MSE and those colored in orange are not covered. The fact that a topic is covered in the MSE means that, applying the method described in the previous section, hours were assigned to it. The units are colored depending on the percentage of topics covered of the same: between 0 and 15%, orange, between +15% and 50%, yellow, between +50% and 85%, light green, between +85% and 100%, green. These colors correspond to the concepts: not covered (NC), partially covered (PC), widely covered (WC) and totally covered (TC). The same that is used for the units is used for the KA but the units are considered instead of the topics. That is to say, that the KA are colored according to the percentage of units covered in them. For this analysis, it is considered that a unit is covered when it is partially covered, widely covered or totally covered.

The example shows that the KA Ethics and Professional Conduct as well as its units and topics are hardly covered in

A - Ethics and Professional Conduct	
Unit	Topic
1 - Social, legal and historical issues	1.1 - Data confidentiality and security, surveillance and privacy
	1.2 - Historical developments, and gender, minor, and cultural issues
	1.3 - Contracts and liability, intellectual property, freedom of information
	1.4 - Computer crime and law enforcement
2 - Codes of ethics and professional conduct	2.1 - Responsabilities to society
	2.2 - Models for professionalism, professional societies
	2.3 - Codes of ethics and practice
3 - The nature and role of software engineering standards	3.1 - Nature and role of standards
	3.2 - International standards, standards and harmonization organizations
	3.3 - Bodies of knowledge, accepted and best practices

Fig. 3. Theme coverage achieved for the KA Ethics and Professional Conduct

Knowledge Area	% of Topics Covered
A - Ethics and Professional Conduct (EPC)	20.00%
B - System Engineering (SysE)	7.69%
C - Requirements Engineering (RE)	90.63%
D - Software Design (SD)	100.00%
E - Software Construction (SC)	100.00%
F - Testing (Tst)	95.24%
G - Software Maintenance (SM)	93.33%
H - Configuration Management (CM)	92.31%
I - Software Engineering Management (SEM)	76.47%
J - Software Engineering Process (SEP)	93.33%
K - Software Quality (SQ)	72.73%

Fig. 4. Theme Coverage at KA Level

the MSE. This allow us to know the coverage of topics, units and KA.

Figure 4 shows the level of theme coverage obtained in each KA using the colors mentioned previously. It also shows the percentage of topics covered for each KA.

Figure 5 shows the unit coverage per KA. For each KA is shows the percentage of units NC, PC, WC and TC. This type of figure allows displaying more detailed information than the one provided in Fig. 4. For example, from the KA that are TC, it can be seen that Software Quality has a significant percentage of units WC. Also, Software Engineering Management KA has a certain percentage of units PC. In both cases opportunities to improve the MSE arise.

Finally, Fig. 6 presents the percentage of units NC, PC, WF and TC from the 55 units defined in GSwE2009. This enables to know the overall coverage of the units. In order to improve the MSE we could, for example, consider the NC and PC units for the creation of new courses or to include these themes into existing ones.

Finally, regarding thematic coverage, of the 202 topics of the GSwE2009, 164 are covered by the MSE. This represents a 81%.

This type of analysis, using colors, makes it possible to have a quick overview of which themes are not widely covered or not covered at all at topic, unit or KA level. This enables us to elaborate new courses which address certain themes not covered or distribute these themes in one or several existing courses if it is deemed that it is necessary and positive to cover them. From the results obtained, the coordinating team of the MSE is working to better cover the KA Ethics and Professional Conduct for the year 2015 with the entrance of the fourth generation of students.

B. Thematic Effort

The thematic effort can be studied at KA, unit or topic level. In this particular case we present the results at KA level because we want to make a comparison with the GSwE2009. The GSwE2009 presents a distribution in percentages of the expected effort only at KA level. Furthermore, it suggests that the CBOK must take about 50% of the time devoted to the Master's Degree in order to achieve the expected Bloom levels. The rest of the time could be used in optional courses (that may or may not aim at covering the CBOK), in courses devoted to covering University specific materials and in the final capstone experience. In our study we consider the real total time per theme (sum of the different types of hours presented previously) and compare it with the expected effort per KA established in the GSwE2009.

As it has already been mentioned, in particular, the GSwE2009 suggests using 200 contact hours to teach the CBOK so as to reach the depth established in the curriculum itself. Besides, the curriculum guidelines set between 2 and 3 individual study hours for each contact hour. Given this, the result is that in order to address the themes of the GSwE2009 with the desired depth, between 600 (200+2*200) and 800 (200+3*200) total hours are required.

In order to divide the expected effort by KA the percentages presented in the CBOK are used (see Fig. 1). These percentages are approximate and that is why they indicate a maximum and a minimum. This is reasonable because of the difficulty (real impossibility) of establishing exact efforts measured in hours to achieve certain levels of knowledge. We used the highest percentage of the range for our analysis, and in this way we try to ensure that the hours our students use in each KA are enough to achieve the expected outcomes referred to the CBOK.

It is our aim that the effort spent on the themes of our MSE be similar to that of the GSwE2009. In this particular case, through the use of the total number of hours per KA, we consider that the effort is similar to that of the GSwE2009

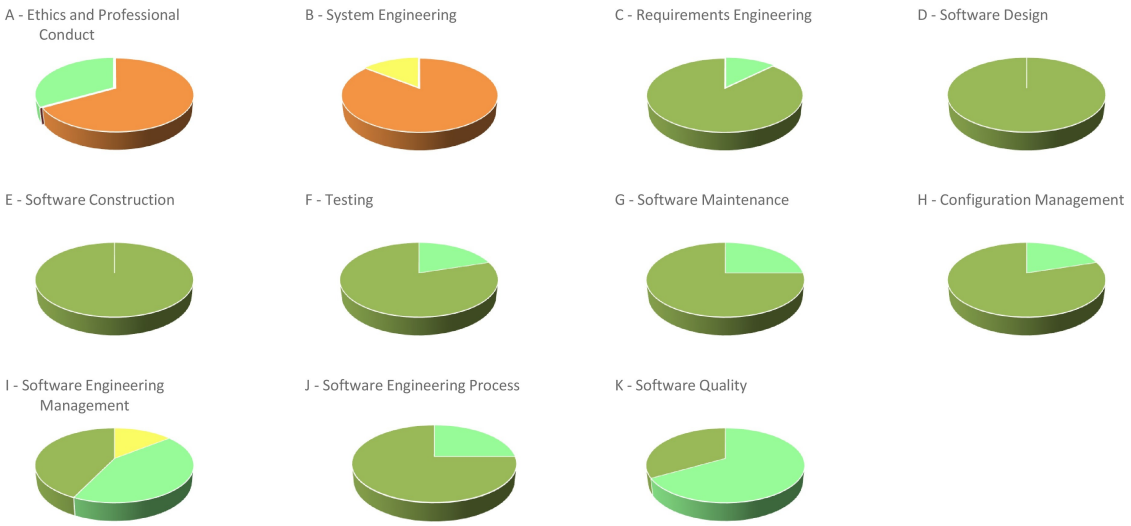

Fig. 5. Unit Coverage for each KA

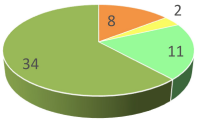

Fig. 6. Units NC, PC, WC and TC

when the hours of the MSE are above the hours suggested by the GSwE2009 using 800 total hours.

In the Table III the results of this analysis are presented. The first column is the KA, the second, the maximum percentage suggested by the GSwE2009 (the sum is more than 50% due to the fact that it is an approximation), the third is the total number of hours in each KA based on a total of 600 hours, the fourth based on 800 hours, the fifth presents the total number of hours calculated for the MSE and the last column a color that represents the satisfaction of thematic effort, compared to the GSwE2009. The red color indicates the fact that the number of total hours is lower than the suggested number of hours using 600 total hours. This means to us that we are far from the desired minimum. The yellow color indicates that a higher number of hours than the 600 hours suggested is used, but not higher compared to 800 total hours. The green color indicates that the MSE hours exceed the suggested hours with 800 total hours, which is what we are aiming at.

This result enables us to know the thematic effort in comparison with the GSwE2009. We can see that there are several KA that are not properly addressed in the MSE. Particularly for the first two already knew this from the previous analysis, but it turns out that although Requirements Engineering is widely covered thematically in its units and topics (analysis of the previous subsection) not enough time is devoted to it so as to be able to address these themes with the depth we intend to achieve. This analysis also provides us with

TABLE III
COMPARISON OF EFFORT IN TOTAL HOURS OF THE CBOK

KA	% by KA	Based on 600 hs (hs)	Based on 800 hs (hs)	MSE (hs)	Compare
EPC	2	12,0	16,0	3,0	🔴
SysE	3	18,0	24,0	1,3	🔴
RE	8	48,0	64,0	44,8	🔴
SD	11	66,0	88,0	156,8	🟢
SC	3	18,0	24,0	67,5	🟢
Tst	6	36,0	48,0	108,3	🟢
SM	4	24,0	32,0	55,0	🟢
CM	3	18,0	24,0	68,5	🟢
SEM	9	54,0	72,0	228,6	🟢
SEP	4	24,0	32,0	80,8	🟢
SQ	4	24,0	32,0	82,0	🟢

opportunities of improvement identifying areas that should have more dedication hours.

C. Thematic Balance

As we already mentioned the CBOK defines the effort distribution at KA level (see Fig. 1). These percentages must be used as a guide and not as a precise specification of a curriculum. In the GSwE2009 50% of the effort is used in non-core curriculum and 50% on the CBOK. Our MSE seeks to allocate the total effort in mastering the CBOK. Therefore, for thematic balance comparison, we use the effort distribution of the CBOK as the 100% of the effort (and not the 50%).

Figure 7 presents in two different ways the balance of the MSE compared to the balance of GSwE2009. The figure from the left shows the maximum and minimum percentages proposed by GSwE2009 for each KA and the percentage of the

total effort (measured in hours) for the MSE. The last column indicates whether the percentage of effort of the MSE is below the minimum, above maximum or between the minimum and maximum percentages proposed by the GSwE2009. The figure on the right shows exactly the same but with a line chart.

This analysis shows that the balance of the MSE differs "a lot" from the balance of the GSwE2009 in the KA of Ethics and Professional Conduct, System Engineering, Requirements Engineering, and Software Engineering Management. In the first three the percentage of effort is lower and in the latter is higher. Also, it can be seen that the rest of the KA have a distribution that could be called adequate. In the Fig. 7 it can be seen how the distribution of the MSE "follows" the minimum and maximum shape of the GsWE2009.

This type of analysis can be used together with the analysis of the thematic coverage and effort. In order to cover the themes that are not covered, or that are not being covered with sufficient depth, new courses should be added or changes should be done in the existing ones. In either cases, this involves changing the balance of the curricula. Then, knowing the balance regarding GSwE2009 helps making decisions. For example, in the case of the MSE, it should be analyzed whether to remove some effort from the Software Engineering Management KA. It could also happen that, for certain reasons, a different balance from the one proposed in the GSwE2009 is wanted. In that case it is good practice to document it.

D. Conclusions on the Evaluation

Evaluating a curricula, and as far as possible, evaluating it continuously, allows continuous improvement. Following the Shewhart PDCA cycle [14] or taking the change suggested by Deming later PDSA (Plan, Do, Study, Adjust), we are currently analyzing (Studying) the data collected in our evaluation of the Implementation of the Curriculum of the MSE. This analysis, that is comparative with the GSwE2009, must be done carefully. The fact that certain themes of the GSwE2009 are not covered does not mean that they should be covered, and the fact that the proportion of the effort indicated by the GSwE2009 might be different from that of the MSE does not mean that the courses should be rebalanced. In both cases, they are simply issues to be to be analyzed carefully so that later, at the Adjustment stage, it is possible to suggest improvements to the MSE (or not).

Curriculum evaluation processes, even more than implementations, are normally long and expensive, and sometimes it is even difficult to establish what to evaluate. In the course of our work we are building an Evaluation Framework of Implementation of curricula based on guidelines or suggestions of international curricula. This framework will allow us to know what could (or should) be evaluated of a certain program that aims at satisfying a reference curriculum. In this work we present three dimensions of this framework applied to the MSE of the UdelaR. This enables us to keep the program under control and to improve it in the future making it possible to plan changes in the short and medium term.

Although our evaluation has limitations, it is clear that it provided us with a lot of useful information and that it gives various opportunities to improve the MSE. At present we are making the adjustments that we deem necessary for the courses of the third generation of students. These adjustments are based mainly on the results collected in this evaluation work.

Other dimensions to build to develop our framework should include other perspectives to evaluate. For example, how the faculty is composed, what skills the students acquire once they finish the degree, what Bloom level a student reaches in each topic introduced during the program, how much the student has improved as far as knowledge is concerned compared to the knowledge they possessed when he entered the program, etc.

VI. Related Works

Since the creation of the SE2004 and the GSwE2009, several universities in the world have used this guide to create their curricula in SE, as well as to adapt, compare and evaluate the existing curricula. Unfortunately, there are few articles published. Below we present the ones we found in our search for related works.

At Gannon University (Pennsylvania), an undergraduate curriculum in SE that aimed at meeting the criteria established to be accredited by the *Accreditation Board for Engineering and Technology* (ABET) that tried to align with SE2004 was designed. For reused courses of previous curriculum the contact hours are indicated and a mapping is done to determine what units of the SEEK are covered [15].

Eleven universities of Turkey that teach undergraduate courses in SE have been compared to the SWEBOK [16]. The analysis compares only the hours suggested by the SWEBOK by KA with the hours devoted in each curriculum of each university to each KA. The hours of the curriculum of the universities are taken from the web pages where the courses are described.

Monash University in Australia developed an undergraduate curriculum in software engineering. The efforts made for the accreditation of the program, its evolution in ten years and comparisons with the SWEBOK and SE2004 are presented in the article "Accreditation of Monash University Software Engineering (MUSE) Program" [17]. The authors evaluated class by class comparing to the themes that are covered of the SWEBOK.

We only found two articles related to adoption and evaluation of GSwE2009 in our bibliographic review. In one of these articles it is presented how four Universities (one of them is ours) in three different countries have used this guide for the construction and adaptation of Master's programs in SE [18]. The other article is our initial presentation of adaptation of the GSwE2009 to create the MSE curriculum [19].

VII. Conclusions and Future Work

In this article we present an adoption and an adaptation of the GSwE2009 for the creation of the curricula of a MSE.

KA	%Min	%Max	%MSE	Comparison
EPC	2	4	0.0	▼
SysE	4	6	0.0	▼
RE	12	16	5.0	▼
SD	18	22	17.0	▼
SC	2	6	8.0	▲
Tst	8	12	12.0	✓
SM	6	8	6.0	✓
CM	4	6	8.0	▲
SEM	14	18	26.0	▲
SEP	6	8	9.0	▲
SQ	6	8	9.0	▲

Fig. 7. Thematic balance

This adaptation respects the reality of information technology in Uruguay, the regulations of the UdelaR and the current situation of the GrIS. In the MSE we aim at covering the thematic contents of the CBOK with the depth established by the GSwE2009.

The fact of having the GSwE2009 as a reference guide facilitated the creation of the curriculum of the MSE and the definition of the courses to be taught. The guide turned out to be flexible.

We also present a method for the evaluation of contents and its application in a real case in the MSE of the UdelaR. This method could be used by other programs who wish to know how the CBOK (or other bodies of knowledge) is covered.

The evaluation of the MSE in thematic coverage, effort and balance provides a notion of the reality in thematic coverage of the MSE as well as various opportunities to improve the implementation of the program. In this sense we detected that two KA are thematically covered in a limited way and that another KA is little covered as regards the expected effort.These results, quantified through the effort of the student to absorb several themes, allows us to obtain a result of the execution of the courses and the program that represents it from a "real" point of view and not from "paper" (study plans and syllabus of each course).

As future work we intend to evaluate the program from other points of view. For example, evaluate the skills acquired by the students during the program or the level of knowledge (measured in Bloom levels) of the different taught topics. This type of evaluation will complement the Evaluation Frame of Implementations of curricula we are constructing.

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