# AN APPROACH FOR AUTOMATED SOFTWARE ENGINEERING COMPETENCE MEASUREMENT: MODEL AND TOOL

*José A. Sánchez[2], José L. Fernández-Alemán[1], Joaquín Nicolás[1], Juan M. Carrillo de Gea[1], Begoña Moros[1], José A. García-Berná[1], Ambrosio Toval[1]*

[1] Department of Informatics and Systems, University of Murcia, Murcia
{aleman, jnr, jmcdg1, bmoros, josealberto.garcia1, atoval}@um.es, Spain
[2] Department of Informatics, University of Oviedo, Gijón
sanchezsjose@uniovi.es
Spain

**Abstract:** Nowadays, competence-based assessment is a term widely used in higher educational institutions. Many educational centres focus their efforts on the concretion of competences for the evaluation. For this purpose, in the European Union (EU) was defined the European e-Competence Framework (e-CF), which provides a reference of 40 competences applied to the field of Information and Communication Technologies (ICT) using a common language of competences, skills and capability levels. On the other hand, the incorporation of Information Technologies (IT) such as Audience Response Systems (ARSs) in the European Higher Education Area (EHEA) or other educational institutions has supposed a new way to teach. Unifying these two concepts (Competences and ARSs), this paper presents a novel approach for automated measurement of competences applied to the field of Software Engineering and shows a description about the conceptual model to develop this type of evaluations. Furthermore, we propose the integration of SIDRA (ARS tool) and SECEIP (Software Engineering Competence Evaluation Internet Portal). This portal will be endowed with a new means of assessing students, thanks to the use of wireless devices, such as, smartphones or tablets.

**Key words:** Software Engineering, Automated Competence Measurement, European e-Competence Framework (e-CF), Audience Response System (ARS)

## 1. INTRODUCTION

Since more than two decades ago, the Competence-Based Assessment (CBA) [1] was proposed as a possible solution in order to evaluate many kinds of people, for instance, teachers, students, employers [2] and, even workers [3]. This sort of evaluation is based on the application of different methods to assess the acquisition of competences by stakeholders. The CBAs are constituted by three essential components [4]: (1) the emphasis on outcomes; specifically, multiple outcomes, separately considered; (2) the belief that the outcomes can and should be specified to the point where they are clear and transparent for the stakeholders; (3) the decoupling of assessment from particular institutions or learning programmes.

In the last years, there has been shift from education centred in teachers to education centred in students [5] provoking a change from the curriculum based on the contents to curriculum based on competences [6]. The CBA is important because we do not evaluate students only using the knowledge, but also we need more parameters such as behaviour, attitude, skills that allow us obtain a precise student assessment. For this purpose, recent studies, such as [7] or [8], propose current assessment trends and methods for assuring good practice in higher education.

Other works, for instance, [9] that performs a qualitative comparison of two frameworks in the evaluation process quality involved in Competence-Based Education or the aforementioned work developed by Gómez et al. [8], that carried out several tests through Competence Assessment using rubrics and oral interviews in the European higher education area in order to learn a foreign language, are examples of different methods to evaluate. As we can see, the assessments do not become a unique method to evaluate students.

In the European Union (EU), Competence-Based Assessment is being used in all education levels, for instance, [10] shows the Competence-Based Curriculum in Spain attending from the primary school to the training of teachers. Their aim is to present the role and application of 21st century competences in the Spanish educational system through the analysis of the primary and secondary curriculum and also that of initial teacher training. Other works in the EU, such as, [11] developed in Austria or [12] performed in Finland, present different evaluation methods in order to study both competence-based teaching and competence areas for students in a high level of education.

Therefore, the Competence-Based Assessment is becoming a relevant aspect in the EU due to high number of educational institutions which used it in many countries. At present, some studies and projects, such as, [13] or the framework for this paper, iSECRET project present big advances in European countries, such as, Belgium, Denmark, Germany, Greece, Hungary, Ireland, Poland, Portugal, Slovakia, Sweden, Turkey, United Kingdom, Latvia, Lithuania, Bulgaria and Spain. Thus, governments have developed a European framework for the competences (European

e-Competence Framework - e-CF[1]), based on the principles about evaluation exposed previously, applying on ICT (Information and Communication Technology) world.

Works about computer science and software engineering based on evaluation of competences have been found in literature. This is the case of [14], authors develop a model based on competences for the area of computer science in the education field.

Focusing on software engineering we found a large research process about the issue of how to schedule this type of education and how to evaluate it. Since 1980 [15], software engineering education had been studied in order to find new methods to teach, learn and obviously assess. Mills discusses the underlying commonalities and the overlaid differences of university and industrial education in software engineering, exploring different methods of evaluations applied to each of them. More recent studies add the competences in the evaluation process, but always in a way to solve the problem founded in a particular case. The paper [16], presents a review of education methods for students in engineering field based on different types of assessments. In particular, they focus on online assessment in the e-learning process or automatic summary assessment for intelligent tutoring systems. Concretely, this work is conducted in the software industry to test competence gaps among software practitioners. Other studies are focused only in the creation of a new proposal for creating a competency profiling model for software engineers and specifically to build a hierarchical structure which will capture different aspects of various competences. This proposal aids ICT companies to reach the optimal decision during recruitment processes and vocational training [17], in other words, how we can assess professional software competences.

Taking into account the different evaluation methods proposed in the revised previous works, we reach the conclusion about the importance of the usage of ICT in the teaching-learning process. Nowadays, the vast majority of the classrooms in the EU have the necessary infrastructure to develop new e-learning system using different tools and applications. One of the most promising technological resources in education is an Audience Response System (ARS) [18]. In educational field ARS is a technology that allows students to answer questions (or full questionnaires) proposed by a professor in real time. In this way, several works, for instance [19] or research developed by Fernández-Aleman et al. [20] [21], perform different analysis of the usage of ARS in higher education in both nursing and pharmacy students at university level. The students expressed satisfaction with the content provided by ARS tools and the methodology used during the process of learning. To the best of our knowledge, no previous work has reported on the use of ARS systems in the software engineering discipline. However, other related work has developed studies about the inclusion of ARS systems in computer science field [22].

[1] http://www.ecompetences.eu/

This paper presents an innovative approach for software engineering automated competence remote evaluation for master program graduates. Our proposal will allow instructors and professors to assess software engineering students by using an ARS called SIDRA[2]. This application has been developed by the Software Engineering Research Group of the University of Murcia. SIDRA has already been tested in several courses from different educational institutions proving it as an appropriate evaluation tool for students. We propose to integrate SIDRA with SECEIP[3] (Software Engineering Competence Evaluation Internet Portal), designed and implemented in the iSECRET (Implementation of Software Engineering Competence Remote Evaluation for Master Program Graduates) project[4]. The SECEIP portal will be endowed with a new means of assessing students anytime and anywhere, thanks to the characteristics of wireless devices such as smartphones or tablets.

## 2. DEFINITIONS AND MODEL

This section presents some key definitions and related concepts. Moreover, the conceptual model designed to allow us to develop our approach is presented.

### 2.1. Definitions

To understand the conceptual model proposed for automated CBA, is necessary to provide some relevant definitions regarding to actual teaching-learning process. For this purpose, we explain the main concepts about it.

- **Qualification**: is understood in accordance with the recommendation of the European Qualifications Framework (EQF) to mean "the formal outcome of an assessment and validation process which is obtained when a competent body determines that an individual has achieved learning outcomes to given standards" [23].
- **Learning Outcomes (LOs)**: Are defined as statements of what a learner knows, understands and is able to do upon completion of a learning process. In the EQF, learning outcomes are therefore defined in terms of Knowledge, Skills and Competence [24].
- **Knowledge**: The outcome of the assimilation of information through learning. Knowledge is the body of facts, principles, theories and practices related to a field of work or study. It includes underpinning theory and concepts, as well as tacit knowledge gained as a result of the experience of performing certain tasks. In the context of the EQF, knowledge is described as a theoretical and/or factual [23].

[2] https://docentis.inf.um.es/sidra/index.php?id=en
[3] http://moodle.kic.teiep.gr/
[4] http://ec.europa.eu/programmes/erasmus-plus/projects/eplus-project-details-page/?nodeRef=workspace://SpacesStore/c50930d7-ab17-41b1-a8d8-0731bbf17b47

- **Skill**: The ability to apply knowledge and use know-how to complete tasks and solve problems. In the context of the EQF, skills are described as cognitive or practical skills [23].
- **Competence**: In the European Qualifications Framework (EQF), a competence is defined as "the proven ability to use knowledge, skills and personal, social and/or methodological abilities in work or study situations and in professional and personal development" [23].
- **European e-Competence Framework (Competence)**: In the terms of the e-CF a competence is defined as "a demonstrated ability to apply knowledge, skills and attitudes for achieving observable results" [25].
- **Rubric**: Educators tend to define "rubric" in slightly diverse ways, but vast majority, such as, [26], [27] or [28], used the following commonly definition: "document that articulates the expectations for an assignment by listing the criteria on what counts, and describing levels of quality from excellent to poor"

### 2.2. Conceptual Model

A conceptual model presents the relationship between different concepts in a schematic representation. The fundamental purpose of the conceptual model is to provide an analytical framework for the examination of the functional requirements. The model focuses on data, regardless of how they are presented.

For the benefits proposed above about the usage of a conceptual model approach and based on definitions described, we have developed a complete conceptual model, showed in Figure 1, in order to give an overview of a competence-based assessment framework using an ARS tool. This model is defined to perform a complete competence-based assessment taking into account all factors and stakeholders involved in the process.

Figure 1, shows a reduced conceptual model in the framework of the concepts involved in the description of a full software engineering program. In this case, we only present the main factors related with the automated CBA and an ARS tool. Moreover, Figure 1 shows the relationship between each module. We can found different relationships between them: 1 - 1 (one-to-one), * - * (many-to-many), 1 - * (one-to-many) and 1 - 1…* (one-to-one or many). Having a bidirectional relationship, the model does not use arrows for their representation.

In the conceptual model developed, we can see the two stakeholders involved in the teaching-learning process, instructors and students. Each instructor may be responsible for one or more subjects that are associated with a unique Rubric for determine the evaluation of the competences. The Competences are composed by 3 aspects: Knowledge, Skills and Attitude. In this case, it is worth mentioning that Competences may be considered as Academic Competences and e-CF Competences, both included in the Syllabus. On the other hand, students perform tests (Test concept) proposed by instructors. A test is composed by one or more questions that are

directly related to the competences. In this way, one competence can define a Mastery Level that is linked with a description of the level of Mastery (DescriptionLevel concept).

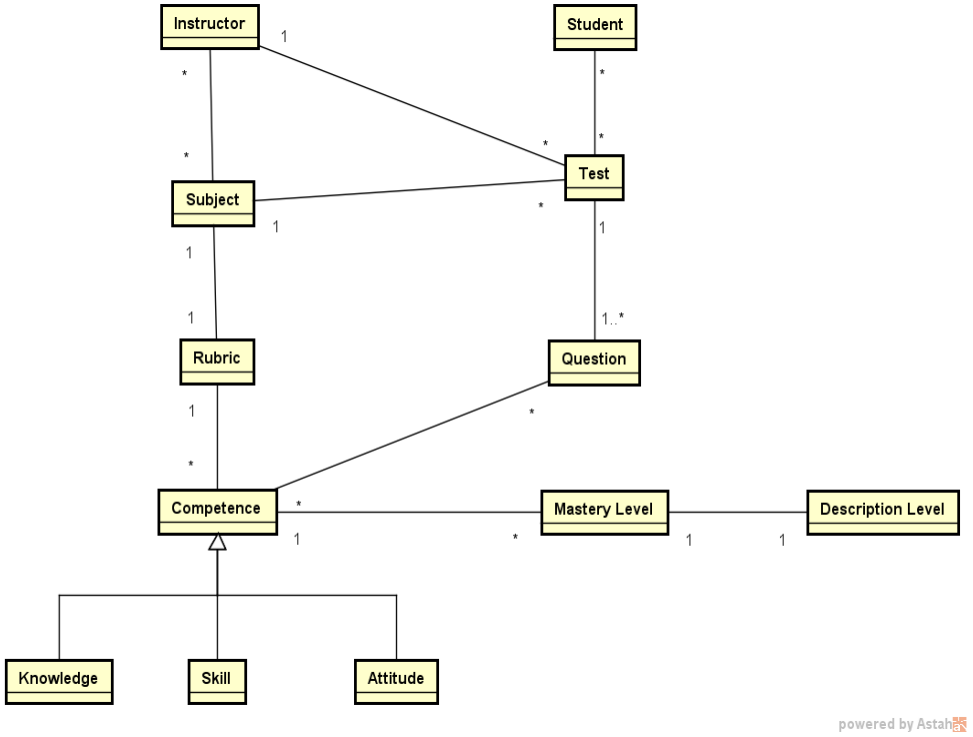


*Figure 1. Conceptual Model*

## 3.AN APPROACH FOR AUTOMATED SOFTWARE ENGINEERING COMPETENCE MEASUREMENT

In this section, we present the SIDRA (*SIstema De Respuesta inmediata de la Audiencia*, in Spanish) tool and the design and implementation of the application. Moreover, we give an approach to use SIDRA for the automated competence assessment and the full integration for our approach. The involvement of both instructors and students in the process of automated competences evaluation will be highlighted.

Considering the usage of SECEIP web portal, the instructor must define the subject's syllabus including basic data, such as title, number of ECTS credits, competences and learning outcomes. To continue, instructors insert a rubric associated directly with the subject in order to define the main criteria to assess and the way to perform it. Criteria defined in each rubric must be associated to one or more compe-

tences. Then, instructors can create one or more tests for each competence, to evaluate students. Finally, instructors assign competences to the questions of which the test is composed.

The student only must take the test using SIDRA tool and answer the questions formulated by instructors. Their responses will be sent to SECEIP portal to evaluate, in an automated process, the competences achieved. Figure 2 shows a block diagram describing an automated evaluation of the competences associated to the test performed by students. In the next section, this concept in a deeper way will be explained.

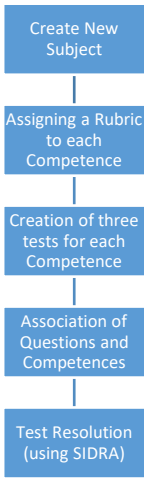


*Figure 2. Block Diagram for Test Resolution*

### 3.1. Audience Response System: SIDRA

SIDRA is a free and publicly available application for Android, IOS, blackberry and Windows Phone. This tool allows a survey taker to create, collect and analyse response to multiple choice questions (MCQs). Therefore, this application allows instructors to achieve relevant information of students in class. SIDRA has a client-server architecture and is designed following the principles of software design in the field of application developments.

The functionality of the SIDRA application is based on a centralized server to which both, students and instructors are connected, recording in a data base all information generated along the complete process. Furthermore, it is worth mentioning that students can use SIDRA with only a personal device with Internet access. Thus, developing a multiplatform application is important. In this way, the application uses HTML5 and CC3 as main technologies with NodeJS and Phonegap (used to develop mobile apps) and PHP for web application.

The ARS is composed by:

- Server: receives the answers of the devices and stores the information in a data base for future reference and analysis of results.
- Web Application: allows any device using a simple navigator to access to SIDRA through both profiles: instructor or student.
- Mobile Application: allows instructors to survey people. In addition, instructors can create and launch a questionnaire or consult the results.

To improve the functionality of SIDRA, the research group developed the i-SIDRA system. This system is based on an intelligent feedback architecture that allows students to perform several self-evaluations and the subsequent revision by the instructor.

SIDRA plays a key role in the description of the approach for automated CBA through the proposition (by instructors) and resolution (by students) of Multiple Choice Question test (MCQ). Figure 3 presents the SIDRA screens for a student to complete a MCQ test. The student is logged in the system to complete a test that has a unique identifier. Finally, the questions (with options) are presented to be answered.

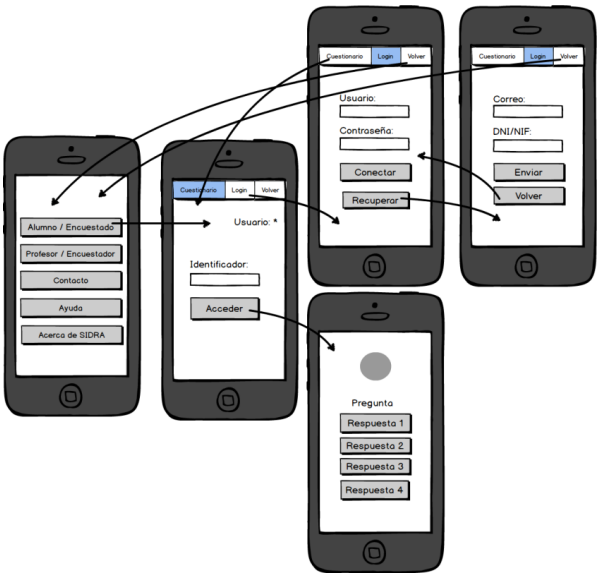


*Figure 3. Stepts to complete a MCQ test by students*

SIDRA is only used in the test resolution, but is also considered in the interaction with the SECEIP portal, designed and implemented in the iSECRET project, to achieve the automation of the competences assessments. At this point, our approach is focused on the integration of SIDRA and SECEIP. The web portal will be endowed not only with the necessary information about subjects, rubrics and associ-

ated competences, but also with new means of assessing students thanks to the characteristics of wireless devices. When students send the answers about a test proposed by the instructor through SIDRA, the ARS send the answers to the SECEIP.

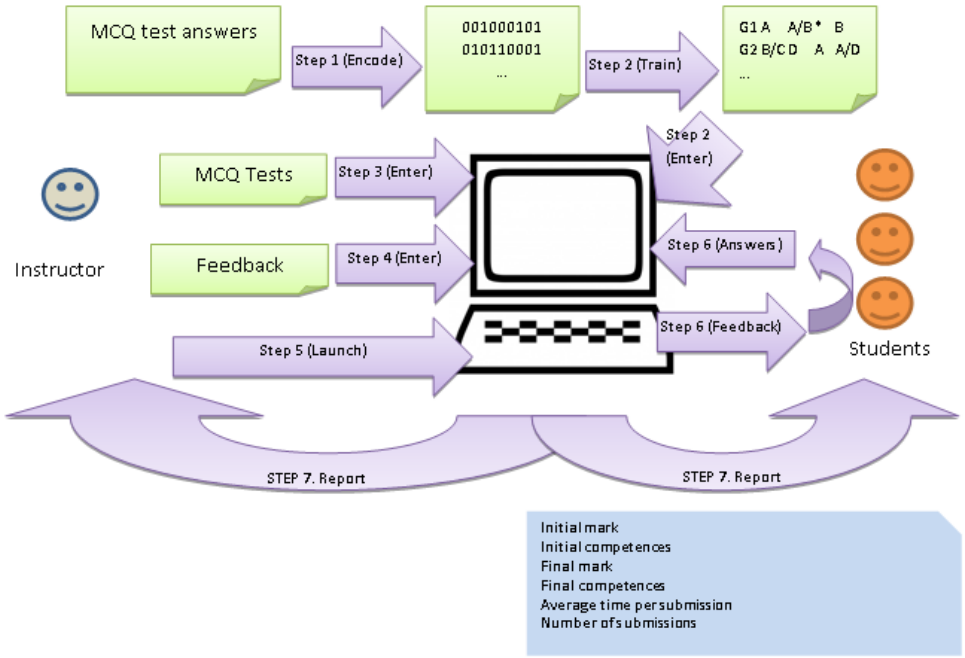


*Figure 4. Use of i-SIDRA integrated in SECEIP portal*

Figure 4 shows an overview of the assessment-learning process by employing i-SIDRA integrated with the SECEIP portal. The following steps are proposed:

*Step 1*. Encode the answers collected in a previous exam.

*Step 2*. Train the neural network with a set of encoded answers. Once groups (knowledge states) are generated, these are introduced in the SECEIP portal. Other clustering algorithms can be used to define the states of knowledge that students may initially have.

*Step 3*. Enter the MCQ tests into the SECEIP portal.

*Step 4*. Instructors must provide diagnostic feedback according to the incorrect answers of the tests. Atomic feedback must be provided for each possible answer to each question included in the questionnaire.

*Step 5*. Tests are launched by the instructor.

*Step 6*. Students receive feedback when answering the questions of the tests through the usage of SIDRA. In this way, the students can change their state and improve their knowledge and competences. This loop finishes when all questions are correctly answered or time is running out.

*Step 7*. A report is generated. Initial mark, initial competences, final mark, final competences, average time per submission and number of submissions are provided. Result analysis can be carried out by the instructor. This report allows instructors and students know how is the teaching-learning process at this point, linking all competences involved in the syllabus.

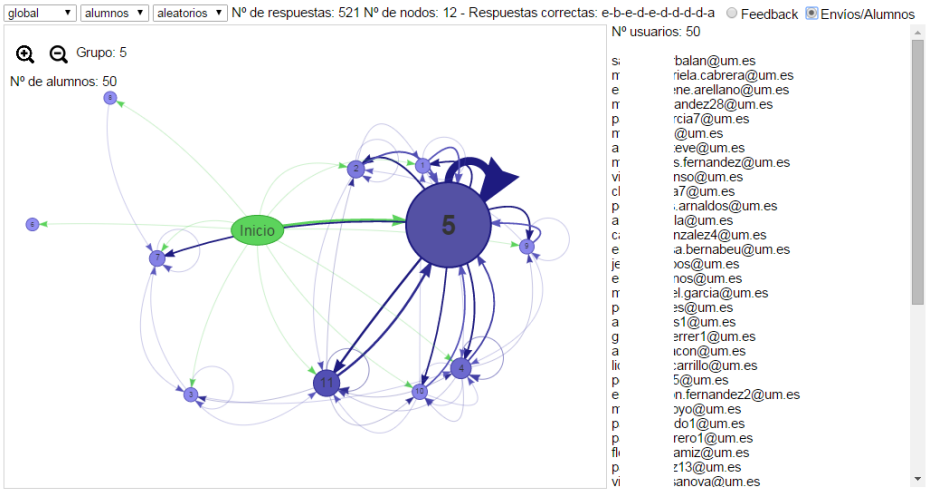


Figure 5. Overall view of the states' graphs per sends and students

A new classification of students from new answers can be obtained (Step 1) or a new questionnaire can be launched. Once the student answers the questionnaire, the instructor can see in a state diagram the evolution of the students. Moreover, relevant information and statistical data can be shown. The instructor can visualize how the student changes from one state of knowledge to another one. Figure 5 shows an example of an overall view of submissions and students, including a knowledge state diagram for a test. At this point, when an instructor clicks in a node, the number of students that have accessed into this group of knowledge appear. On the right, a list of student of this node is presented. The color of each node represents the total number of students that have accessed to this state, the more students the darker the node.

The application has been tested in some related works in order to contrast the functionality and feasibility of the proposed system [21] [20] [29].

## 5. CONCLUSION

In this paper we have presented a new proposal for automated competence-based measurement in the Software Engineering field. Firstly, we have proposed a Conceptual Model for the competence-based assessment and the use of SIDRA tool as an automated evaluation method through Multiple Choice Questions (MCQs).

Other main factor is the interaction between SIDRA and SECEIP in order to achieve the complete automated competences assessment.

Due to the importance of the competence-based assessment in the educational field, we consider that the use of an appropriate tool such as SIDRA (ARS), can help us to know the degree of competences which the student acquires by the completion of different test included in a subject definition.

As we have studied in this paper, the competence-based assessment already existed, but we introduced an innovative approach to automate the process through the use of ICT systems. In this way, we obtain a computerized register about competence measures and the complete description of the level of competence acquisition by students. This novel approach will expedite the evaluation process and reduce the time spent by instructor in the manual competence evaluations.

It has been demonstrated that the competence evaluation is fundamental in the teaching-learning process for both, instructors and student. Through the approach presented in this paper, we can conclude that this type of evaluation is valid not only for software engineering field, but also for other educational sectors and levels in which are involved the competence-based measurements.

## ACKNOWLEDGEMENTS

The research is part of the project “Implementation of Software Engineering Competence Remote Evaluation for Master Program Graduates (iSECRET)” run by University of Murcia, contract No. 2015-1-LV01-KA203-013439, co-financed by EC ERASMUS+ program. This research is also part of the project GINSENG (TIN2015-70259-C2-2-R) supported by the Spanish Ministry of Economy and Competitiveness and European FEDER funds.

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### *Information about the author(s):*

**José A. Sánchez** – He is a Computer Science Engineer and MSc on New Technologies in Computer Science from the University of Murcia (Spain) with a PhD in Computer Science from the University of Oviedo (Spain). His main research areas of interest are related to Intelligent Transportation Systems, Vehicular Networks, Driving Efficiency and Telematics Environments.

**José L. Fernández-Alemán** – He is an associate professor at the University of Murcia, where he is a member of the Software Engineering Research Group. He received his BSc (Hons) degree in 1994 and his PhD degree in 2002, both in Computer Science from the University of Murcia.

**Joaquín Nicolás** – Dr. Joaquín Nicolás Ros is an Associate Professor in the Department of Computer Science and Systems at the University of Murcia, Spain. He received B.Sc. and Ph.D. degrees in Computer Science. Currently, his main research interest is in requirements

engineering, concerning reuse-based requirements engineering, global software development, education, usability and sustainable processes.

**Juan M. Carrillo de Gea** – He is a Research Associate and Adjunct Professor at the University of Murcia, Spain. His current research interests include requirements engineering, requirements reuse, global software development and empirical software engineering. He is also involved in other research lines, principally e-health and e-learning.

**Begoña Moros** – She is a Lecturer at the Department of Computer Science, University of Murcia (Spain). She has a background in model driven engineering, requirements models and requirements traceability. Her current research interests include green computing, in particular how to foster sustainable software development by means of green requirements specifications and processes.

**José Alberto García Berna** – He is a PhD student at the Department of Computer Science and Systems of the University of Murcia. His research interests are Requirements Engineering and Project Management, specifically Green Software Engineering and Sustainability in Information and Communication Technologies.

**Ambrosio Toval** – He is a full professor at the University of Murcia, in Spain. He holds a BS in Mathematics from the University Complutense of Madrid, and received a Ph.D. in Computer Science (cum laude) from the Technical University of Valencia (both in Spain). He is involved in a variety of applied research and development projects with industry and conducts research and technology transfer in the areas of requirements engineering processes and tools, privacy and security requirements and applications in the e-health, e-learning and mobile development domains. He has published in the same topics in international journals, such as IEEE Software, IST, REJ, Computer Standards & Interfaces, IET, IJIS, etc. Dr. Toval is currently the Head of the Software Engineering Research Group, at the University of Murcia.

**Manuscript (final revised version) received on 10 September 2017**