Research in Software Engineering: Paradigms and Methods

María Lázaro and Esperanza Marcos

Kybele Research Group
Rey Juan Carlos University
Madrid (Spain)
{mlazaro, esperanza.marcos}@urjc.es

Abstract. Software Engineering (SE) is a field without too much historic background. The youth of the SE discipline is resulted in an immaturity of this research field and SE research still lacks suitable scientific precision. Moreover, in SE research there are several objects of study with different nature each of them and, for this reason, different research and validation methods are needed. In view of this situation, we discuss the nature of the SE, trying to identify different kinds of research problems this discipline deals with. As hypothesis, and according to the nature of the research problem to be broached, we propose a classification of the research problems of the SE discipline in: those with a *Scientific nature* and those with an *Engineering* nature. We try to justify this hypothesis on the basis of the paradigms and the research process which is in general used for the resolution of these kinds of problems.

1 Introduction

Software Engineering (SE) is a field without too much historic background since it is less than four decades old. This idea can be supported by means of the fact that its first publications and conferences were held in the late 1960s [4] (in the 1950s there was certain research but it was covered of confusion and without any significant publication) and its academic presence did not begin to separate from Computer Science until the early 1980s; this event meant a important fact in SE research developing [8]. This youth of the discipline of SE is resulted in an immaturity of this research field. This immaturity is verified because research which is carried out in this discipline has several deficiencies [21, 22, 25] like the lack of systematic rigorous method, the lack of the evident methods of validation, etc. We can say SE research still lacks suitable scientific precision (meaning Science in a wide sense of the word and without drawing a distinction between Science, Engineering, Technology, etc.).

Besides, each scientific discipline has a certain object of study which distinguishes the process to be followed in the research. The problem of SE research basically takes root in the fact that it is not so evident which the object of study is or rather the problem is that there are several objects of study with different nature and so, there are also different research and validation processes. This problem is motivating a rising concern with research methods and the validation in SE [6, 8, 10, 15, 18].

In this paper we discuss the nature of the SE, trying to identify different kinds of research problems this discipline deals with. We propose, as hypothesis, a classification of the issues of the SE discipline in: those with a *Scientific* nature and those with an *Engineering* nature. Each of these two kinds of problems deal with different kinds of objects of study. Whereas the latter deals with the problem of building new software artefacts, the former focuses on theoretical bases of the SE. We try to justify this hypothesis on the basis of the paradigms and the research process which is in general used for the resolution of these kinds of problems.

We are fully aware of the disagreement that the classification and the definitions (even the names) given above can bring about. However, the paper aims at inducing in this way to the debate about these opened questions.

The rest of the paper is organised as follows: section 2 discusses the nature of SE research proposing, as hypothesis, a classification of research problems in this discipline; section 3 tries to justify the hypothesis on the basis of the research paradigms and processes; section 4 presents the main conclusions and future works.

2 Nature of SE research: Science and Engineering

The nature of SE research, basically Science or Engineering, depends on its object of study. Seen this way, and according to the object of study, the research process will be different so that the kinds of problems can be tackled by means of different research methods and even by means of different paradigms.

However, which is the object of study of the Science in contrast to the object of study of the Engineering? The fundamental difference between Science and Engineering is that while the Science pays attention to natural aspects, the Engineering is concerned with artificial aspects [1]; that is to say, while the former deals with the study of what things are like, the latter is concerned with what they should be like in order to make it possible to construct new objects. Nevertheless, both Science and Engineering are knowledge and action since in the same way Science is also action, not just knowledge; correlatively, we may say that Engineering is also knowledge, and not just application. The difference between Science and Engineering lies in the modes of knowledge and action that they develop, not in one of them knowing and the other applying [15]. In other words, Science and Engineering will differ in the research process which is used in each one [23]. Therefore, Engineering research differs greatly from traditional scientific research because while Sciences deal with the study of existing objects and phenomena, be it physically, metaphysically or conceptually, Engineering is based on *how* to do things, *how* to create new objects.

Applying this reflection to SE, how do we consider it, like Science or like Engineering? Opinions by several authors [2, 13] are not conclusive, being necessary some prerequisites so that SE can be a real Engineering [19]. To answer this question we take as reference point other fields with a bigger historic background and, also with more maturity, such as Electronics, Chemistry or Geology; in such fields we may

talk as Science as Engineering. So, in the same way Electronic Physics and Electronic Engineering, Chemistry and Chemical Engineering, Geology and Geological Engineering coexist and making a simile with these fields, we can say that SE has a double nature, of Science and Engineering, depending on the object of study; this fact determines the research process. Therefore, *Software Science* (using Blum terminology [3]) comes from Computer Science and pays attention to the aspects that have to do with the study of built artefacts, like code or other kind of artefacts such as models, documents, etc; this Science deals with problems such as algorithmic complexity, software metrics, testing techniques, etc. On the other hand, we can find another kind of research problems (Engineering problems), supported by *Software Science,* concerned with the creation of software artefacts and we could define it as the study of transforming ideas into operations [3].

So, whereas *Engineering* problems deal with the creation of new artifacts, *Scientific* problems deal with the study of existing ones. Note, that an Engineering problem becomes a Scientific problem once the object has been created; when a new artifact is created (for example a new model), by an Engineering research process, this new artifact becomes an existing one being an object of study by a scientific research process (for example, studying its correctness, its quality, etc.)

Although there are other classifications of problems in SE, these classifications are not appropriate since they are not focused on the research process. Thus, for instance, the SE Body of Knowledge project (SWEBOK [20]) sets out areas as: Software design, Software construction, SE tools and methods, etc. This schema is accurate enough but it is mainly centred on the creation of a body of knowledge with educative aims. Then, it provides invalid areas of knowledge for a classification of research problems because we can find scientific and engineering problems in each area. In this regard, for example, in SE tools and methods area, it is not the same trying to create a new method than testing a previously created method. In Software design, you can either create new models to improve the design process or study existing models and analyse their implantation and use in a company. We notice the former case is an Engineering problem while the latter case is an empirical or socio-cultural problem but all of them are included in the same area of the SWEBOK. This inclusion into the same area makes its difference in the research field impossible.

Concluding, we propose a classification of the research problems of the SE discipline in two kinds, which differ in the nature of its object of study: those with a *Scientific* nature and those with an *Engineering* nature. As both kinds of research problems have different objects of study, they should use different research paradigms and different research methods.

3 Justification of the classification

We can justify the classification scheme we have set out by means of the research process which is use in each case [9]; we analyse: a) the research paradigm; and b) the research method.

3.1 Research paradigms

To carry out research in any previously-mentioned field, it is important to set out a paradigm for any research a researcher wants to realize. Thus, we may consider descriptive paradigms (evaluative-deductive or positivist paradigm, evaluative-interpretive or interpretive paradigm, evaluative-critical or critical paradigm, etc,) and formulative paradigms (formulative model, formulative-process, method, algorithm, etc.) [8]. These paradigms change depending on nature of the research problem: Scientific or Engineering.

To broach *Scientific* research problems, evaluative paradigms are the most used, either positivist paradigms (used in empirical sciences) or interpretive or constructive paradigms (used in social and cultural problems). In this regard, for instance, we could apply positivist paradigms to testing or interpretive paradigms to organisation processes which are necessary for the implantation of a tool. Although there are other paradigms, even combinations of paradigms which can give rise to mixed paradigms, they always present characteristics which allow us to include them in a behavioural-Science research paradigm [11].

On the other hand, to broach *Engineering* research problems, descriptive paradigms are used and these paradigms interact with positivist and interpretive paradigms [10]. Thus, for instance, by means of literature reviews the researcher can try to establish the weak spots of a model and its respective technique of creation and afterwards, can try to establish a description of a new technique and the new built model.

3.2 Research methods

Depending on the kind of problem to solve and the context of the problem, Science or Engineering, different research methods are used [5], [7]. Moreover, scientific research methods can not always be applied to engineering research problems [16].

Scientific research problems are similar to problems broached in traditional sciences and can have either an empirical or a cultural and social nature. When the Science has an empirical nature, quantitative research methods can be applied [12]; these methods try to solve problems like: “what model method is more efficient?”. When the Science has a social and cultural nature, qualitative research methods can be applied [17] and these methods can seek to answer questions like: “what factors make a given software process unacceptable to the company?” or “why is one information systems development tool more acceptable than another?”. In both, it is necessary certain knowledge of the reality: the object of study is an existing object in the world. Thus, this kind of problems use the research methods proposed by traditional sciences, as they study phenomena and objects of the world regardless of how they were created.

However, there is not any precise method to broach *Engineering* research problems and the search for a method appropriate to this field is becoming a research field in its own right [6], [8], [10], [17], [18]. The solution of problems purely concerning Engineering requires methods of a different kind since in these cases it is directly

possible to apply neither empirical methods nor methods which have to do with social and cultural component as the object of study does not yet exist [24]. Furthermore, in the case of Engineering, it is necessary a major component of **creativity**, which makes it difficult to draw up a universal method for solving problems within this field. For instance, "what research method would be valid for the specification of a new methodology for software development?". It would be necessary to study existing methodologies, reflecting on them to determine their advantages and disadvantages and proposing a new one, which, while retaining the advantages of the methodologies studied, would, as far as possible, lack their shortcomings. Arriving at a better final proposition would largely depend on the creativity and common sense applied to the construction of the new method. This method is proposed by [13] and it is stated the method it is applied in Engineering consist in the formulation of experiences and the identification of the best practices.

4 Conclusions

Summing up, we can say that we can distinguish two kinds of problems in the SE research: *Engineering* problems, concerned with the construction of new objects, and *Scientific* problems, concerned with the study of the existing object. In its turn, *Scientific* problems include two kinds of issues: the study of the object in the strict sense and the study of its implantation and interaction with the context.

This classification has been obtained by means of the study of the research paradigms and processes. We notice paradigms in Science are different from paradigms in Engineering; these paradigms give rise to different research methods, emphasizing the fact the creativity must be always present in Engineering area, being a characteristic of the research independently from the method. It is due to the Engineering research method always has as objective the construction of new objects.

Finally we have found a great deal of similarities between the research process in *Engineering* problems and the software development process; nowadays, we are working in a comparative study between both processes.

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