

An Approach to the Integration of Qualitative and Quantitative Research Methods in Software Engineering Research

María Lázaro and Esperanza Marcos

Kybele Research Group
Rey Juan Carlos University
Madrid, Spain
{maria.lazaro, esperanza.marcos}@urjc.es

Abstract. Two distinct research methods coexist in SE: quantitative methods, which seek to measure and analyze causal relationships between variables in a framework with free values, and qualitative methods, which examine the process of creating meanings from which new or improved theorems are generated. Applying these two methods separately to SE research, it becomes clear that the results obtained are incomplete and thus it is difficult to definitively choose between quantitative and qualitative methods when embarking on a specific research. To address this problem, a new research method based on integrating quantitative and qualitative methods is proposed.

1 Introduction

Research in Software Engineering (SE) has become increasingly important. It has grown from being a disorganized field without standard journals to having an important presence in the academic world [6]. This fact is due to the youth of the discipline of SE. This youth of discipline makes Software Engineering (SE) is always creating needs (organizations are incorporating SE more and more and their demands are not always adequately met) and these needs have to be satisfied through the investigative process. However, research in SE is still in an immature stage and the lack of a systematic and rigorous methodology is noticeable. There is also the need for clear methods to validate and verify results, etc. Therefore, it might be said that research in SE lacked sufficient “scientific” rigor [16], [21], [22], [23].

Regarding methods, research in SE has been based mainly on the quantitative perspective, except in the field of Information Systems, where the qualitative perspective has been accepted for quite some time thanks to the need to deal with the complexity of human behavior [3], [14], [20]. Nevertheless, as the human factor is present in practically all the fields within SE, the use of qualitative methods to address this behavior has become a need. Under these circumstances, a dilemma arises: what would be best to use, quantitative research methods or qualitative research methods? In certain situations, the answer is easy and the researcher is inclined to use one or the other of the methods, but in the majority of cases the choice is not so simple. For

instance, if we want to research the efficiency of several chips to different temperatures using the number of tasks chips can process per hour, we use a quantitative research method of two factors: the type of chip and the different temperatures. On the contrary, if we want to analyse how to improve the effectiveness and efficiency of a project team, we use interviews, surveys, etc. and data will be analysed above all using nets and matrixes. In this case, the experiment will be utterly qualitative. Nevertheless, if we want to analyse the efficiency of a certain paradigm (time of construction of an application) depending on the program language within a project team, we will need a quantitative experiment with two factors: paradigm and type of language and a qualitative experiment to study the human factor. This qualitative experiment will show us the reasons for the quantitative results.

To address this problem, this article discusses the differences between the qualitative and quantitative methods and tries to find a solution to the problem of choosing an SE research method. As a starting point and hypothesis, a research method is proposed that implies the integration of qualitative and quantitative methods. The hypothesis will be verified on the basis of paradigms and generally accepted knowledge, examples and on the work of different authors who in different ways have sought to justify such integration.

The article is structured in the following way: section 2 discusses the application of qualitative and quantitative methods, and establishes as a starting point, a possible integration of said methods to solve research problems in this field; section 3, begins a justification of the hypothesis based on the work of different authors and on the basis of existing paradigms; and section 4 summarizes the main conclusions and suggests future lines of research.

2 Quantitative Methods vs. Qualitative Methods

The *quantitative method* proposes to measure and analyze causal relationships between variables within a framework of free values [6]. It is based on the positivism that supports empirical research since all phenomena can be reduced to empirical indicators that represent truth. This fact is due to the existence of one truth and is independent of human perception. Therefore, the investigator and the thing investigated are independent entities.

Hence, quantitative research methods work with data in numerical form collected from a representative sample and analyzed usually through statistical methods. The ultimate objective is to identify the dependent and independent variables, eliminating inadequate variables, and in this way reduce the complexity of the problem so that the initial hypothesis can be confirmed or discarded.

The *qualitative method* examines the process of assigning meanings. It is based on interpretation and constructivism, taking into account that there exist multiple realities and multiple truths based on the construction of a social reality that is constantly changing. Therefore, the investigator and the object of study are interactively intertwined in such a way that discoveries are created mutually within the context of the situation that molds the investigation [6], [11].

Furthermore, qualitative research methods mainly analyze visual and textual data in such a way that the sample is restricted to just a few or even only one example. Hence, this type of method allows the complexity of the problem to be confronted, keeping in mind that results are not the objective. Rather, the goal is to be able to generate new theorems or improve existing ones.

Opposite to what might be inferred from these definitions, one can not always definitively choose between quantitative and qualitative methods. Accordingly, the choice of the method to apply in SE research is itself becoming a subject of investigation [8], [9], [10], [17], [18]. We begin with the hypothesis that the integration of the two methods could be the best option in some problems dealt with in SE research. These situation would be Engineering problems not Scientific problems because according to the object of study (both kinds of research problems have different objects of study), the research process will be different and the kinds of problems must be tackled by means of different research methods [16].

To study if this is true, their integration is analyzed in the following section.

3 Integration of Quantitative and Qualitative Methods

In this section, we have to keep in mind the current controversy in the social sciences on choosing to use either qualitative or quantitative methods and that this debate seems to be now being resolved, according to several authors [1],[2], [5], [7] through the integration of qualitative and quantitative methods. Thus, in the same way, it is here proposed that the integration of qualitative and quantitative methods be implemented in SE research.

The real possibilities to integrate are those that arise in the social sphere since this is a pioneering area in experimentation with qualitative and quantitative methods at the same time. Hence, the most frequent situations to integrate qualitative and quantitative approaches are (see figure 1):

- *Complementation*, where each operation is capable of revealing different, interesting zones of reality due to quantitative and qualitative research is carried out separately and afterwards, in the last stage, they are joined to complete each other [2].
- *Combination*, which seeks to achieve complementary results using the strength of one method to improve another and carrying out an experiment first and the other after the knowledge of the first results. Most frequently, a qualitative pilot study is followed by a quantitative investigation [2].
- *Cross-validation or triangulation*, which combines two or three theories or data sources to study the same phenomenon and thus gain a more complete understanding of said phenomenon. In other words, the obtained quantitative or qualitative data will be validated by the other data since the type of results should be the same.

The first two research methods can be considered independent methods; the third is interdependent [2].

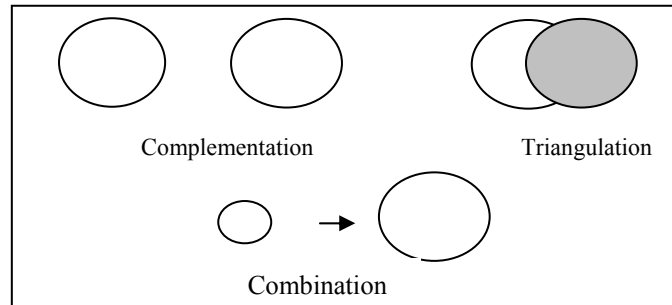


Fig. 1. Schematic representation of the types of integration

Anyway, a more detailed explanation can be found in [2].

This classification underlines the importance of integration by complementation since, remembering that quantitative and qualitative methods do not study the same phenomena, integration of the two methods to make proposals of cross validation/triangulation is not a viable option (cross validation is usually useful in the combination of the two approaches to study the same phenomenon) On the other hand, combining the two approaches in a complementary manner is not a good idea if the ultimate objective is to study different aspects of the same phenomenon because the this method can not hope to enhance the phenomenon being studied. Therefore, the best choice is for the qualitative and the quantitative methods to be integrated, but each method should study different phenomena (complementation) since any other procedure will cause the loss and falsification of the information [2].

Nevertheless, the integration method that understands complementation in this way is ambiguous. As a result, it was necessary to find a more precise complementation integration method. The steps to be taken are the following:

1. Use quantitative techniques, and list their deficits in the results: to do this, it is necessary to analyze and check for the influence of the operational conditions in the result obtained through the experimental technique chosen.
2. Investigate why these results were obtained with quantitative methods, through the use of qualitative methods that allow social aspects to be emphasized.
3. Last, integrate the quantitative and qualitative processes to obtain complete results that include both technical aspects as well as social and cultural aspects. To this end, both qualitative and quantitative results have to be carefully analyzed as well as any possible integration techniques that allow an overall result to be obtained from partial results obtained with each of the techniques.

More precisely, the following steps are taken:

1. First, do a quantitative experiment without an accompanying qualitative experiment.

2. Study the quantitative experiment in an overall way, above all with regard to hypotheses and results but without extreme precision.
3. Generate questions that the researcher thinks are necessary to record qualitative data in relation to previous study of the quantitative experiment. This data recording will be done through interviews, surveys, observation, etc.
4. Redo the quantitative experiment but now include a qualitative experiment.
5. Analyze the results obtained in the quantitative experiment, verifying them with the previously obtained results.
6. Analyze the results obtained in the qualitative experiment, keeping in mind the previous analysis of the quantitative experiment:
 - If the quantitative results of the two experiments coincide, the qualitative results will be analyzed, with the objective of explaining these results.
 - If the quantitative results of the two experiments vary, the cause of the variance will be investigated.

It must be remembered that this first qualitative experiment will only serve as a first approach and that its results are not definitive.
7. Go back and re-plan both experiments, keeping in mind the previous results.
8. Study the quantitative experiment in a detailed way, especially the proposed hypotheses and the results obtained, which are necessary for planning the qualitative analysis. Based on this study, redo the planning of the qualitative experiment, by eliminating the questions that do not allow results to be obtained, by modifying those questions whose formulation is not clear, and by creating new formulations that improve the obtained results.
9. Carry out the new quantitative and qualitative experiments.
10. Analyze both the quantitative and qualitative experiments.
11. Propose a final experiment in which the quantitative and qualitative parts are joined. In other words, there are no limits in design and the two parts must perfectly complement one another.
12. Analyze the results of the last experiment, making final conclusions.

Table 1. Summary of the steps in the integrated method.

Step	Description	Step	Description
1	Quantitative experiment	7	New approach to quantitative experiment
2	Study results of quantitative experiment	8	New approach to qualitative experiment
3	Preparation of qualitative questions	9	Do qualitative/quantitative experiment
4	Do qualitative/quantitative experiment (approximation experiments)	10	Analyze quantitative/qualitative results
5	Analyze quantitative results	11	Plan integrated experiment
6	Analyze qualitative results	12	Analyze results

4 Justification and Validation of the Proposed Method

A review of the bibliography on this subject provided a group of criteria to use to justify the proposed method. The criteria for choosing this method were the following:

First, the two approaches should be integrated because the goal of both is to explain the world in which we live [12] and both seem to share a unified logic and the same rules of inference [15].

Second, said methods are united in their shared commitment to understand and improve the human condition, their common goal to disseminate knowledge for practical uses, and their mutual dedication to rigor, conscience, and the critical process of investigation [19].

Third, as observed previously [4], the integration of research methods is useful in some research areas because the complexity of phenomena requires information from a great number of perspectives. Thus, some researchers have mentioned the complexity of the majority of social interventions requires the use of a wide spectrum of qualitative and quantitative methods.

Fourth, and our final point, until now in SE mostly quantitative techniques have been applied, and they have been shown to be insufficient. Therefore, the integration of qualitative and quantitative methods seems to be an appropriate solution.

On the other hand, if one looks closely at the research paradigms, just as there are evaluation paradigms for quantitative and qualitative methods, called positivist (for the empirical sciences) or interpretative or constructive (for problems with a larger social and cultural component), there are authors [10], [13] who propose mixed paradigms for social-technical development that supports the possibility to integrate methods.

Table 2. Summary of the paradigms used in the SE research process.

Paradigms utilized	Type of problem	Example
Positivist Paradigm	Empirical	Compare two methodologies to develop Web Information Systems (WIS) to determine which of them gives the user a more intuitive navigational map.
Interpretative-constructive Paradigm	Social and cultural	Determine why a methodology to develop WIS cannot be implanted in a specific organization.
Descriptive Paradigm	Technical	Create a methodology to develop WIS that gives users more intuitive navigational maps than those obtained by applying currently existing methodologies.

5 Conclusion

In conclusion, it is noted that in SE research there exist two distinct methods: quantitative methods, that are used to measure and analyze causal relationships between variables within the framework of free values, and qualitative methods that are used to generate new theorems or improve existing ones.

In current research, above all there is a tendency to prefer technical investigation, or, from a different perspective, there is a lack of interest in using the social aspect in the analysis process that is a part of all research. This means that SE research concen-

trates on emphasizing technical topics instead of behavioral topics and, in cases where it examines the social side, it ignores the technical aspects.

Therefore, if the two SE research methods are applied separately it is observed that the results obtained are incomplete. Hence, it is difficult to choose definitively between quantitative and qualitative methods for a specific research.

Using integrated qualitative and quantitative methods in SE research is suggested as an appropriate way of addressing this problem, and here a first approach to a new research method is proposed that is similar to the implementation of integrated qualitative and quantitative methods in the social sciences. Specifically, of the three types of integration taken from the field of social sciences, complementation is chosen, and this modified and redefined for improved usage in the field of SE.

In summation, it must be pointed out that a more concrete application is needed to be able to examine our results in a more detailed way. At the present, research is being done in this regard in the SE field, although more studies will be needed to find a totally generic method that offers an indication of when to use quantitative methods, qualitative methods or an integrated method.

Acknowledgements

This work is framed in the MIFISIS project (*Research Methods and Philosophical Foundations in Software Engineering and Information Systems*) supported by the Spanish Ministry of Science and Technology (TIC2002 - 12378 - E) and the GOLD project supported by the Spanish Ministry of Education and Sciences (TIN2005-0010).

References

1. Alvira, F. "Perspectiva Cualitativa, Perspectiva Cuantitativa en la Metodología Sociológica". *Revista de Investigaciones Sociológicas*, 22,1983,pp 53-75.
2. Bericat E.: *La integración de los métodos cuantitativo y cualitativo en la investigación social*, Ariel sociología, Barcelona, (1998).
3. Chen, W., Hirschheim, R.: A paradigmatic and methodological examination of information systems research form 1991 to 2001. *Information Systems Journal* 14 (2004) 197-235.
4. Clarke, P. N., Yaros, P. S. Research Blenders.: Commentary and Response. In Sale, J. E. M., Lohfeld L. Brazil K.: *Revisiting the Quantitative-Qualitative Debate: Implications for Mixed Methods Research*. *Quality and Quantity*, 36, (2002).
5. Conde, F. Una propuesta de uso conjunto de las Técnicas Cuantitativas y Cualitativas en la Investigación Social. *El Isomorfismo de las dimensiones topológicas de ambas técnicas*, REIS, Madrid, 1987, 213-224.
6. Denzin N. K. y Lincoln, Y. S. *Handbook of Qualitative Research*. In Sale, J. E. M., Lohfeld L. Brazil K. *Revisiting the Quantitative-Qualitative Debate: Implications for Mixed Methods Research*. *Quality and Quantity*, 36, (2002).
7. Delgado, J. y Gutierrez J. (coords) *Métodos y Técnicas Cualitativas de Investigación en Ciencias Sociales*". *Síntesis Psicología*, Madrid, 1994.

8. Dobson, P. J.: The Philosophy of Critical Realism-An Opportunity for Information Systems Research. *Information Systems Frontiers*, 3(2), (2001) 199-210.
9. Glass, R.L., Vessey, I., Ramesh, V.: Research in Software Engineering: an analysis of the literature. *Information and Software Technology. Elsevier Science B.V. N. 44*, (2002) 491-506.
10. Gregg, D. G., Kulkarni, U. R., Vinzé, A. S.: Understanding the Philosophical Underpinnings of Software Engineering Research in Information Systems. *Information Systems Frontiers*, 3(2), (2001) 169-183.
11. Guba E. G., Lincoln, Y. S. Competing paradigms in qualitative research. In Denzin N. K. Y Lincoln Y. S, *Handbook of qualitative Research*, Thousands Oaks, Sage, (1994).
12. Haase, J. E., Myers, S. T. Reconciling paradigm assumptions of qualitative and quantitative research. In Sale, J. E. M., Lohfeld L. Brazil K. *Revisiting the Quantitative-Qualitative Debate: Implications for Mixed Methods Research. Quality and Quantity*, 36, (2002).
13. Hevner, A. R., March, S. T.: The Information System Research Cycle. *IEEE Computer*, 36 (11), November, (2003),111-113.
14. Kaplan, B., Duchon, D.: Combining qualitative and quantitative methods in information systems research: A case study. *MIS Quarterly* 12 (1998) 571-586.
15. King, G., Keohane, R. O, Verba, S. *Designing Social Inquiry: Scientific Inference in Qualitative Research*. In Sale, J. E. M., Lohfeld L. Brazil K. *Revisiting the Quantitative-Qualitative Debate: Implications for Mixed Methods Research. Quality and Quantity*, 36, (2002).
16. Lázaro M., Marcos, E.: *Research in Software Engineering: Paradigms and methods. Workshop on philosophical Foundations of Information Systems Engineering, CAISE, Oporto*, (2005).
17. Marcos, E., Marcos, A.: An Aristotelian Approach to the Methodological Research: a Method for Data Models Construction. *Information Systems- The Next Generation*. L. Brooks and C. Kimble (Eds.). Mc Graw-Hill, (1998), 532-543.
18. Myers, M. D.: Qualitative Research in Information Systems. *MIS Quarterly*, 21(2), June, (1997), 241-242.
19. Reichardt, C. S., Rallis, S. F. Qualitative and quantitative inquiries are not incompatible: A call for a new partnership. In Sale, J. E. M., Lohfeld L. Brazil K. *Revisiting the Quantitative-Qualitative Debate: Implications for Mixed Methods Research. Quality and Quantity*, 36, (2002).
20. Seaman, C. B.: Qualitative methods in empirical studies of software engineering. *IEEE Transactions on Software Engineering* 25 (1999) 557-572.
21. Tichy, W. F. Lukowicz, P. Prechelt L., Heinz E.: Experimental Evaluation in Computer Science: A Quantitative Study. *Journal of System Software*.28(1), (1995), 9-18.
22. Tichy W. Should Computer Scientist Experiment More? 16 Reasons to Avoid Experimentation. *IEEE Computer*, 31, 5 (1998).
23. elkowitz M. V. Wallace D. Experimental Models for Validating Technology. *IEEE Computer*. 31, 5, (1998),23-31.