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Introducing Empirical Software Engineering Methods in Education

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Abstract

Empirical methods are important in software engineering. It is important to be able to evaluate new techniques and methods in a structured way before they are introduced in the software process. This paper presents how empirical methods may be taught by letting students take part in the execution and analysis of empirical investigations in projects. The projects that the students carry out include a role-play where teachers play the roles of managers for the students and responsible for ordering the work of the students. It is reported from an evaluation where it is found that the project is well received and that it is probable that the students reach the related learning objectives of the course.

1. Introduction

Empirical methods have gained increased attention in software engineering. There are dedicated conferences such as the International Conference on Empirical Assessment in Software Engineering (EASE), and there are journals such as the International Journal of Empirical Software Engineering. The area has been recognised as important in both research and in industry. It is necessary for researchers in both computer science and software engineering to evaluate their research results in practice and it is necessary for industry to evaluate new techniques and approaches as a step of introducing them in their working processes.

As in many other applied research fields there has been a connection between education and empirical methods in software engineering. In many cases software engineering students and computer science students are involved in empirical studies carried out by researchers. This is also the case in, for example, psychology. However, the objectives of these studies are primarily to investigate the area covered by the empirical study, and not to teach the students in empirical methods.

Many engineers are, in their practice, faced with problems of changing techniques or methods in software development organisations. It could for example be that the organisation wants to change their tool for project planning or their technique for inspecting object oriented designs. This kind of decisions must be made based on some kind of investigation of the appropriateness of the new technique in the specific organisation. No technique or method fits in every situation, project or organisation. That is, there is a need to teach students how empirical studies are carried out, and this could be covered in courses that are given at universities. Further on, the area of process implementation and change is high-lighted as one important area in the Software Engineering Body of Knowledge [1].

The outline of this paper is as follows. In Section 2 the area of empirical methods in software engineering is shortly presented. In Section 3 it is described how empirical methods have been taught in one specific software engineering course, and in Section 4 experiences from this course are presented. In Section 5, conclusions are summarized.

2. Empirical methods

Empirical methods can be carried out in different ways, for example in controlled experiments, case studies, and surveys [2]. They are often run in a number of steps, see for example [6], which may be summarized into *planning*, *execution*, and *analysis*. These steps are shortly described below with a focus on controlled experiments.

2.1 Planning

In the first step the study is planned and the design of the study is decided. If it is a controlled experiment where a number of approaches or techniques are compared, the following two types of factors are defined:

- Independent variables: These variables describe the "treatments" that the participants should be subject to in the study. For example, if a study has the objective to compare two CASE tool, T1, T2, the independent variable describes the choice of tool and it can take two values: T1, T2.
- Dependent variable: This is the variable (or variables) that describes the impact of the different values of the independent variable. For example, it may be the required effort for a development task or the number of introduced faults in the code.

The design of the study should follow some basic principles, e.g., randomization (which participants that receive each treatment should be decided randomly) and balancing (there should be equally many participants that receive each treatment).

2.2 Execution

In this step the participants of the study carry out the work that results in measurements that can be analysed. For example, if two tools should be compared, half of the participants may use one of the tools and the other half may use the other tool when conducting a defined task.

2.3 Analysis

If the empirical study is a controlled experiment, the objective of this step is to decide if there is an effect of the independent variables on the dependent variables. This is often carried out by applying hypothesis testing. That is, applying statistical tests to determine whether it is possible to reject the null hypothesis (that there is no effect) with a certain statistical significance.

It is, of course, also necessary to interpret and draw conclusions from the study. It is also necessary to evaluate the threats to the validity of the study that are present.

3. Introducing empirical methods in a course

Empirical methods have been introduced in a software engineering course at Lund University. In this section the course is presented, and in the next section the project assignment, that involves empirical methods, is presented.

3.1 The software engineering course at Lund University

The objectives of the course can be summarized as:

- Knowledge objectives: The objective of the course is to give an introduction to the area of software engineering. The student should obtain knowledge of available methods, techniques and tools used in software engineering.

- Skills objectives: The student should know how to use available techniques and methods to master problems that are encountered during industrial software development. The student should also know how to choose methods to use in different situations in software engineering.
- Attitude objectives: The objective is that the student should obtain an understanding of the complexity of software development and an understanding of the importance of an appropriate and defined software development process.

The area of empirical methods is primarily covered by the skills objective that "the student should also know how to choose methods to use in different situations in software engineering".

The course includes (spring 2001) lectures and assignments around the material in a standard software engineering text book [3], and a project which covers empirical methods in software engineering. The estimated time required for the students in the course is in total 4 weeks. The course is not compulsory in any educational programme. Instead it chosen by students who are interested in the area.

3.2 Required knowledge for the course

The required pre-condition for students who follow the course is that they have taken basic courses in programming and statistics. This is because we believe that some knowledge of programming is necessary in order to understand the concepts in the course, and some knowledge of statistics is necessary in order to understand how empirical studies are carried out.

Even if it is not required, most students have before the course followed a project course in software engineering in which they have been working in groups of 17 persons with the objective to add new functionality to a large software system [5]. In that course they follow a waterfall process model and they have roles such as project manager, verification and validation manager, requirements- and system manager, developer, etc.

3.3 Project assignment

The course includes a project with the objective that the students should gain knowledge of how to evaluate new techniques and methods in a software developing organisation. The students work in groups of 5 persons and they should use empirical methods in order to be able to formulate recommendations for a large hypothetical software developing organisation. Every year there are about 45 students, which means that there are about 9 projects that are carried out in parallel. Most years there are about 3 different *project areas* (e.g., evaluation of review techniques, evaluation of estimation techniques, evaluation of pair programming), which means that there are about 3 groups that carry out projects on the same area.

The work is arranged as a role-play where the students and teachers play different roles. The work is carried out with two virtual organisations:

- A Software Development Company (SDC),
- A company with expertise in empirical methods, i.e. an Empirical Method Company (EMC).

The virtual organisations do, of course, not exist in reality. However, it is based on the project course (see Section 3.2) that most students have followed before the course. This is further described in Section 3.6.

3.4 Execution of empirical studies

The projects are carried out in two phases, before the formal start of the project and after the formal start of the project. Before the formal start of the project, all the empirical studies are planned

and executed. For every project area in the course there must be one session where the execution of the study takes place. The studies are planned by the teachers and all studies are executed in one week. Students are randomly assigned to a number studies. In most cases this means that each student participate in the execution of two different studies. Which study the student participates in has nothing to do with which project area the student should be working with after the formal start of the project.

For example, if there are three different project areas, there must be three sessions with execution of studies. If there are 45 students, and every student should participate in the execution of two studies, there are 2*45/3=30 students that participate in the execution of every empirical study. This means that there is a reasonable chance to obtain statistically significant results if, for example, the objective of the empirical study is to compare two different code review techniques.

Before the formal start of the project, when the empirical studies are executed, the students are not told so much about how the project should be carried out, or about the role-play in the project. They are told that there should be projects later on in the course and that the empirical studies that they participate in are necessary in order to be able to carry out the rest of the project.

3.5 Role-play

In the role-play, which starts at the formal start of the project, it is said that the students work with EMC and have been assigned a project area where they should help SDC to improve in their work. The following roles are defined:

- *Project member*: This role is taken by the students that work in the project groups. One of the students in every group is the project leader. The project members are with EMC.
- *Manager*: This person is, as the students, with EMC. It is a person that has experience in the area and that can help the students. This role is played by the teaching staff of the course, and there is one manager for every project group.
- *Customer*: The customer is with SDC, and is responsible for ordering the project from EMC. This role is played by the teaching staff of the course. There is one customer for every project group.

3.6 SDC - Software Development Company

SDC is the hypothetical organization that is ordering all the projects from EMC. The students are told that the persons at the company have plenty of work to carry out at SDC, but the customer has promised to attend a number of meetings with them.

As it was stated above, SDC is based on the project course [5] that most students have followed before the course (see Section 3.2). In this section, SDC is presented as it is presented to the students as part of the course.

SDC consists of 5 departments, concerning software development, which are directly subordinate to the CEO (Figure 1).

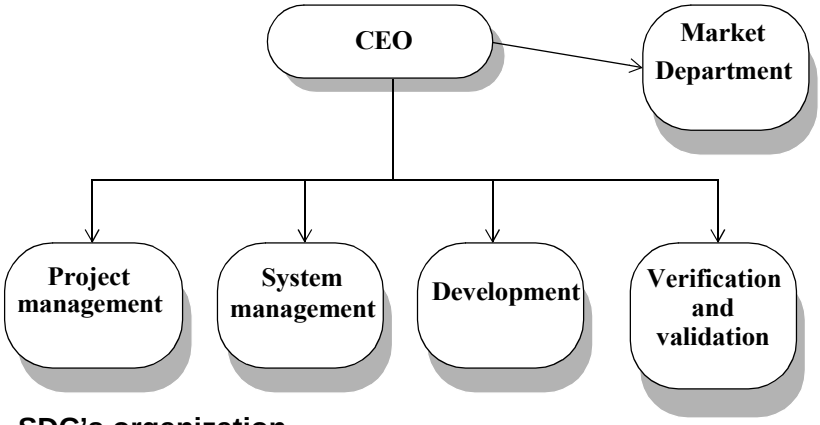


Figure 1. SDC's organization.

The departments are specialised in different areas. Four departments are specialised in active participation in software development projects:

Several development projects (i.e. the project groups in the project course) are carried out in parallel. Personnel from each of the project management department, the system management department, the development department, and the verification and validation department participate in each project.

In every development project four groups are formed (see Figure 1):

- One project management group with staff from the project management department.
- One system group with staff from the system management department.
- One development group with staff from the development department.
- One verification and validation group with staff from the verification and validation department.

The hypothetical organisation is based on the project course that most students have followed before the course (see Section 3.2) in a number of ways:

- The roles in the projects at SDC are the same as in the project course.
- The number of parallel projects at SDC is the same as in the project course.
- The domain of the projects at SDC is the same as in the project course.

It is, for obvious reasons, impossible to let students carry out empirical investigations in real companies. By basing a virtual organisation on a course that most students have followed, the intention is that they should be able to understand the organisation. The intention is that this should make the work as similar as possible to a real empirical investigation, carried out in a real organisation.

3.7 EMC - Empirical Method Company

In the role-play, the students are working at this hypothetical company. EMC will, based on a contract with SDC, specify the exact work that should be carried out. The price has been negotiated and EMC has undertaken to perform the work within a given time frame. The work is supposed to be carried out by five employees (i.e., the project group).

3.8 Budget and project plan

The budget in terms of person hours for each project is as follows:

- Project members: 200 hours (5 persons * 40 hours)
- Manager: 10 hours

As described in the next section, some of the budget (5*4=20 h) is devoted to participation in the execution of empirical studies prior to the formal start of the project.

Based on the budget, the project group is expected to write a plan which also serves as a contract. The students should prepare a first version of the plan after a few days of the project. The plan describes the commitments of the project group, and any deviations from the plan must be discussed with the manager.

It is the responsibility of the students to use the available time in the best possible way. The students are told that the manager does not carry out any of the project work.

3.9 Meetings

Most of the contact between the teaching staff and the students are at a number of planned meetings. The meetings are summarized in Table 1.

Table 1. Meetings

Meeting	Participants	Description
Formal start of project	Project members Manager Customer	This meeting is carried out in two major steps. First the customer presents the problem and answers questions that the students have. Then the customer leaves the meeting, and the manager presents his/her view of the project area. This meeting is held with all project groups that should work with the same project area.
Weekly meetings	Project members Manager	This meeting is typically held once a week at the teacher's office with one project group at a time. The project group has the opportunity to ask questions and get help from the teacher (manager).
Mid-project meeting	Project members Manager Customer	This is a meeting in the middle of he project between one group and the two teachers (manager, customer) that are involved in the project. The main objective of the meeting is that the students should have a chance to meet the customer and fine-tune their plans for the second half of the project.
Executive briefing	Project members Manager Customer	The objective of this meeting is that the students should present the result of their project for the customer, the manager (i.e. the teachers) and the other students. This is also a feedback session to the students that participated in the execution of the empirical studies before the formal start of the project.

Most students (and teachers) speak Swedish in their daily life. In order to make the role-play more pronounced it is said that all communication (written and spoken) with the customer should

be in English. In this way, it is obvious when a teacher is acting as a customer and when he/she is acting as a more traditional teacher in the other parts of the course.

3.10 Involvement of the students in the empirical studies

From a learning objective the intention is that the students should be involved in the empirical studies as much as possible. The best would, of course, be if the students were able to carry out all the steps in the study, from planning to analysis. This is, however, not possible since it would require too much time within the course. If the students decided the design of their study, it would also mean that there would be one design for every group of students. Then it would be necessary for every student to participate in very many studies in the execution phase, otherwise there would not be as many subjects as necessary in every study in order to have a chance to receive significant results.

Instead of letting every group of students plan their study, the design of the studies are decided by the teachers. This means that the students can participate in the execution of the studies before the formal start of the project, and that more than one group can analyse the results from one execution session.

At the formal start of the project the student groups are given the data from the execution of the project and a description of how the study was carried out. Their first assignment is to describe how the study was designed and then they should analyse the data and determine threats to the validity of the results. In this way the students work with questions from all three phases of the empirical study, even if the focus is mainly on the analysis-phase after the formal start of the project.

The objective of the students in the project is to give recommendations to the SDC company concerning how they can improve in the area of the empirical study. The recommendations should include two parts:

- Recommendations directly related to the empirical study. For example, if the study concerns a specific review technique, the students could recommend the company to start using the technique or they could recommend the company not to start using the technique.
- More general recommendations. This could, for example, include *how* a new technique can be introduced and a survey of alternative techniques.

4. Experience from introduction

Empirical methods have been introduced at two occasions in the course at Lund University as described in Section 3.

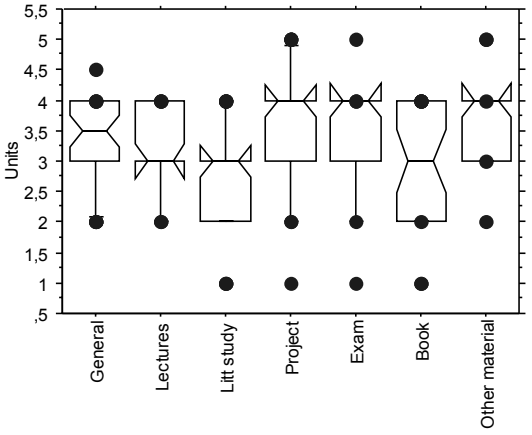
4.1 Project areas

The areas that have been investigated in the projects have all been chosen in order to be appropriate for elaboration in the short time frame. The occasion when the students are working with the execution of the studies is maximum 2 hours for every project area.

Both controlled experiments and other empirical studies have been performed in the course. An example of a controlled experiment that has been performed is an evaluation of pair reviews, i.e., reviews carried out in pairs. In the execution of the study the students were grouped into small groups, where half of the groups consisted of two persons and half of the groups consisted of one person. All groups were then given the same review assignment. The objective of the empirical study was to determine whether there is a difference between how many faults the groups with one person and the groups with two persons find.

4.2 Evaluation

The impression from the teachers of the course is that the project with the empirical studies is one of the parts in the course that gives the most to the students. When the course was given in 2001, an evaluation of the different elements of the course was done through a questionnaire to the students. They were asked to grade the different elements (and the course in general) with a number 1-5, where 1 is the worst grade and 5 the best. A summary of the grades are presented in box-plots and in tabular form in Figure 2.



	Count	Minimum	Maximum	Median
General	36	2,000	4,500	3,500
Lectures	31	2,000	4,000	3,000
Litt study	36	1,000	4,000	3,000
Project	36	1,000	5,000	4,000
Exam	33	1,000	5,000	4,000
Book	36	1,000	4,000	3,000
Other material	31	2,000	5,000	4,000

Figure 2. Course evaluation results.

Box-plots [4] describe the median value and the spread of a data set. They are further described in Figure 3.

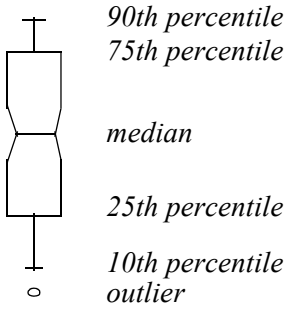


Figure 3. Box-plots, legend

The moments/aspects of the course that is presented in Figure 2 can be further described as:

- General: Here, the students were asked to grade the course in general.
- Lectures: This concerns the lectures that were given in the course.
- Literature study: This concerns an assignment where the students were asked to summarize a section of the text book [3] and to present the summary for the other students.
- Project: This concerns the project with the empirical studies as presented above.
- Exam: This concerns the written exam in the course.
- Book: This concerns the text book [3].
- Other material: This concerns, for example, web-pages of the course.

From Figure 2 it can be seen that the project is well received by the students compared to the other moments in the course. More details on the results of the evaluation with respect to the

project can be seen in the histogram in Figure 4. It can be seen that most students gave the project the grade 4, although some students gave it a higher or lower grade.

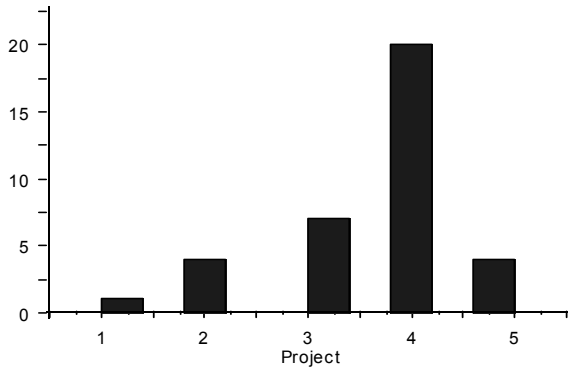


Figure 4. Evaluation results for the project assignment.

It should be noted that the evaluation that has been carried out is based on the grades that the students have given the parts of the course. It can, of course, not be guaranteed that a high grade reflects that students learn much in the course. However, the interpretation here is based on that high grades are good and low grades are not so good. We also believe that, in most cases, a course part must be well received if learning should be accomplished as effective as possible.

5. Conclusions

We believe that the projects with the empirical studies give the students experience from investigations and that the work is well received by the students. We believe that the students become aware of that it is possible to carry out valid investigations of new technology before it is introduced.

The impression from the course is that the students work with the area of empirical investigations in a way that gives more experience and knowledge, than just reading about this kind of studies in a text book. We also believe that we have been able to reach at least the application level of Bloom's taxonomy[1].

Acknowledgments

The author would like to acknowledge the work of all other persons who have been or are working as teachers in the course. Especially the work of Prof. Claes Wohlin, Dr. Björn Regnell, and Dr. Anders Wesslén has been very important. The author would also like to thank Dr. Per Runeson for reviewing the paper.

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