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Achieving Industrial Relevance in Software Engineering Education

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Abstract

This paper presents a collection of experiences related to success factors in graduate and post-graduate education. The experiences are mostly concerned with how to make the education relevant from an industrial viewpoint. This is emphasized as a key issue in software engineering education and research, since the main objective is to give the students a good basis for large-scale software development in an industrial environment. The presentation is divided into experiences at the graduate and postgraduate levels respectively. For each level a number of strategies to achieve industrial relevance are presented. These strategies have been successful, but it is concluded that more can be done regarding industrial collaboration in the planning and conduction of experiments and case studies. Another interesting strategy for the future is a special postgraduate programme for people employed in industry.

1: Introduction

A key issue in university software engineering education is to achieve industrial relevance. With industrial relevance we mean that the education prepares students so that they are ready to cope with large-scale software development. It is also important that students are aware of the challenges and proven techniques related to industrial development of software. This is crucial as software engineering implies large-scale software development, which means that the focus is primarily on engineering aspects rather than on a specific design method. Specific methods are needed, but they should be viewed from a larger perspective when they are applied. Thus, we must have a comprehensive view of software development, instead of looking for silver bullets [1]. We would like to embrace the definition of software engineering according to IEEE [2], that is “software engineering means application of a systematic, disciplined, quantifiable approach to development, operation and maintenance of software”. In particular, this means that software education is not only about software design methods and programming languages. We must be able to teach aspects such as requirements engineering, process improvement, software testing and software quality just to name a few important areas. This poses a challenge as the areas are rather difficult to learn solely through reading software engineering literature. Thus, ways are needed that allow us to emphasize the industrial relevance, and in particular the application of sound engineering principles to the development of real software.

The industrial relevance is important at both undergraduate, graduate and postgraduate education. In the Swedish system, undergraduate refers to a Bachelor degree, the graduate education results in a Master’s degree, and the postgraduate education includes a Licentiate degree and a

Ph.D.. The differences are further discussed in Section 2, where a background to the Swedish system is provided to explain the context of the experiences presented.

This paper highlights some opportunities and experiences of software engineering education. The objective is to present and inspire educators to consider different alternative ways of performing education in software engineering. Most of the ideas are applicable to other areas as well, but the experiences are from software engineering.

The focus is primarily on approaches that we have applied to make both the graduate and postgraduate education relevant from an industrial perspective. In the graduate education, the education is primarily provided in large classes with 30-130 students taking the courses. This poses some specific problems as it is not feasible to provide a personal education for each individual. This is, however, possible at the postgraduate level, where the students are employed at the department and participate in research projects. Thus, different ways to achieve industrial relevance and stress the need for engineering of software have to be found. The objective here is to present our experiences of some different approaches we have identified. We will present experiences from both graduate and postgraduate education.

The paper is organized as follows. In Section 2, the background of the students entering the graduate and postgraduate education is given to provide a context of the experiences presented. Important aspects and some tested strategies to obtain industrial relevance in the education for both postgraduate and graduate education are presented in Section 3. The presentation starts with the postgraduate level as it provides some essential information for the graduate level. In Section 4, some of the experiences are highlighted and some future possible directions to further improve the education is discussed.

2: Background

2.1: The Department and the Master programmes

In Sweden, a Master's degree in engineering corresponds to 4.5 years of full-time studies, which is equivalent to 180 Swedish credit points (i.e. one year equals 40 credit points). At Lund University, there are 9 Master's Programmes in engineering, and software engineering is involved in two of them, i.e. Electrical Engineering and Computer Science & Engineering. It is normal to enter Master's Programmes after nine years of compulsory education and 3 years of upper secondary education at an age of 19-20 years. Undergraduate studies resulting in a Bachelor's degree are carried out at other parts of the university. At an Institute of Technology, most of the students go directly for a Master's degree. Thus, our department is primarily involved in graduate and postgraduate education, although we have lately been more and more involved in a new undergraduate programme in Software Engineering.

The Department of Communication Systems is one of 15 departments providing courses for students following the Electrical Engineering or Computer Science & Engineering Programmes. The number of employees in the Department is 25, including academic staff, postgraduate students, and administrative and technical personnel.

The Department gives nine courses within the Master's Programmes. The Master's courses range from telecommunications courses to theoretical courses in queueing theory, and three of the courses are software engineering courses. The Department has traditionally focused on systems analysis, and in particular, performance analysis of telecommunication and computer networks. In the middle of the 1980's, it was, however, realized that it was not possible to teach a system view of large systems without taking the software into account. Thus, it was decided to provide a

number of software engineering courses, with a particular focus on large-scale software development, where the software development process was judged to be a critical success factor.

2.2: Graduate students in the Master Programme

The software engineering courses are optional in both the Master's Programme in Computer Science & Engineering, and for the students in Electrical Engineering who have chosen to specialize in telecommunications. The courses are normally taken in the fourth or even fifth year, with a few students taking them in their third year. This means that the students are very familiar with computers, programming and mathematics. They have completed a number of courses in mathematics, statistics, physics and electronics, which, of course, are combined with a number of courses on computers and computer science. The computer science courses, which are of particular interest, include programming with different paradigms, compiler technology and object-oriented design. The students have worked in software development projects, but normally only with design and programming issues. A number of the students taking the software engineering courses normally pursue their Master's thesis work at the Department.

2.3: Postgraduate students in the Licentiate and Ph.D. Programme

The students entering the postgraduate education are normally recruited from the students having a Master in either Electrical Engineering or Computer Science & Engineering, and they have typically focused on the courses provided by the Department and also performed their Master's thesis at the Department. A postgraduate student is normally employed by the Department, unless they are industrial postgraduate students. This is further discussed in Section 3. The postgraduate students are thus viewed as part of the staff at the Department, and they participate normally in a research project which usually provides some funding. Some postgraduate positions are, however, provided by the university and no other funding is required, but for most postgraduate positions external funding is required. The external funding implies that the actual research is determined by the projects for which we manage to get external funding. External projects can either be funded by government agencies or companies.

The postgraduate programme includes two degrees, Licentiate and Ph.D.. The Licentiate degree consists of one year full time courses and one year of research work, which are presented in a thesis. A Ph.D. is received after another half year of courses and an additional one and a half year of research work. The Licentiate work is included in the Ph.D. degree (The Licentiate degree can be viewed as "mid-term exam" corresponding to "half" Ph.D.; all the Ph.D.'s graduated at the department also have a licentiate degree.). Thus, a Ph.D. degree means that you have taken one and a half year of courses after your Master's degree, together with two and a half years of research work which are presented in a dissertation, and defended at a seminar. The actual division between courses and research studies may differ slightly between different departments. But, in general, it means that a Licentiate degree equals two years work and a Ph.D. is four years of full time studies. The average time to finish a degree is, however, normally longer as the postgraduate students are expected to contribute in the work at the Department, for example, as teachers in courses at the graduate level.

The postgraduate students are supervised by a professor or associate professor during their research studies. The professor is normally responsible for formulating the research questions and applying for funding of the research projects.

3: Important aspects and tested strategies

In our work to achieve industrial relevance in our software engineering education, we have identified a number of important aspects to address. We have also tested a number of strategies in our teaching work which we have found successful. The important aspects and the tested strategies are summarized in Figure 1 below. The aspects and strategies are divided between the graduate (Master) programme and the postgraduate (Licentiate and Ph.D.) programmes.

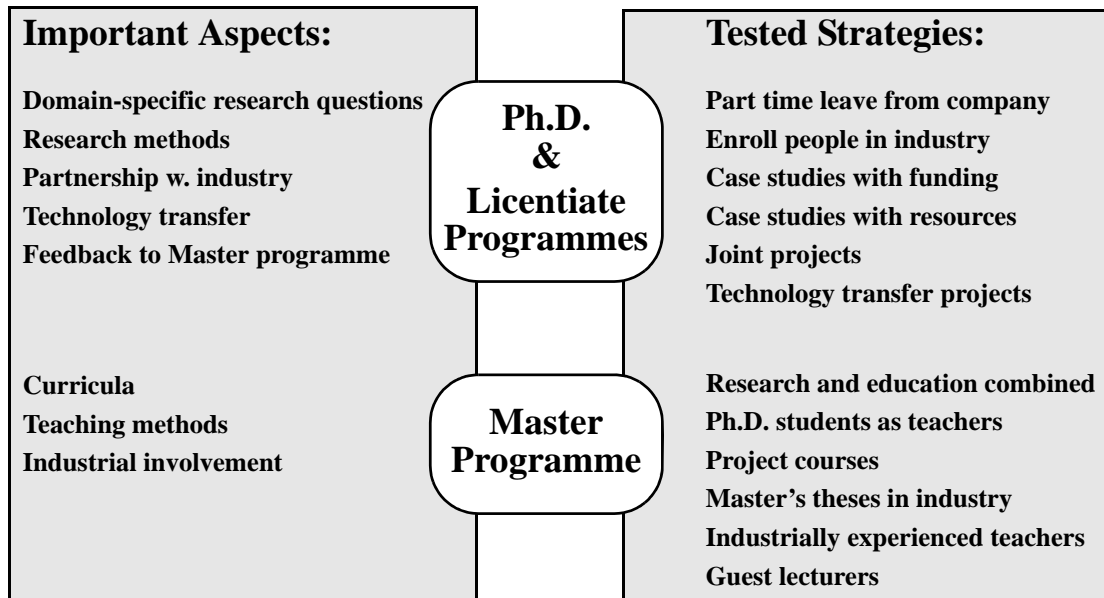


FIGURE 1. Summary of important aspects and tested strategies for industrial relevance in software engineering education.

3.1: Licentiate and Ph.D. Programmes

This section outlines a number of aspects in software engineering research which we have found important in order to achieve our objectives of providing industrially relevant research and postgraduate education. First, we will present a number of aspects which we have found important based on our experience, then some of the aspects will be highlighted through some examples of strategies that we have tested together with our postgraduate students in their Ph.D. studies at the Department.

Based on our experiences the following aspects are important for successful postgraduate studies in software engineering, where successful means (1) industrially relevant research, (2) the results are easy to publish, and (3) the students accomplish their degrees.

- *Domain-specific research questions at an application-oriented department.* Most software engineering research is probably conducted at a computer science department. We have not conducted any formal study, but based on experiences from looking at the affiliation of people at conferences and of authors in journals we think this is a fair statement. We have, however, found that there are benefits with conducting software engineering research at an application-oriented department. This does not mean that the research should not be carried out at a computer science department. We would rather like to stress that there are other opportunities and that they can be successful. Our Department is focused on telecommunications as its main

application area, and some of the research is directly aimed at solving research problems faced by the telecommunication industry. Thus, the research being conducted is in itself applied. Software engineering research is inherently applied, hence from this perspective it fits well into the Department. Moreover, the focus on telecommunications provides a natural application area for the research results. The objective is that the research results should be generally applicable, but we have come to the conclusion that telecommunications provide a good starting point for evaluating our research results. Another benefit with a specific application area, in our case telecommunications, is that the Department has good industrial contacts in this area based on its special focus.

- *Research methods.* A key aspect is the research methods used. We do not believe that we can continue to present new methods without being able to have some empirical evidence. Thus, we need to use empirical methods in our software engineering research, which means that experimentation [3] and case studies [4] are essential to succeed. Experimentation is important as it provides a better understanding of the methods investigated, and it also works as an important step before it is possible to transfer any research results for broader use. Case studies are an important tool to identify research questions, and as a way of monitoring industrial software development. In particular, they can be used as a means for introducing new technologies and evaluating the outcome before and after a specific change in, for example, the software process.
- *Partnership with industry.* A close relation with one or several industrial partners is crucial to enable the postgraduate students to perform case studies in industry, and to have a natural environment for evaluating new research results. Furthermore, it is important to have a close relation with industry when identifying important research questions to ensure that we, as researchers, address relevant research questions. The research group in software engineering has an active collaboration with ten companies involved in software development. Moreover, the department takes an active part in regional, national and international collaborative networks. The networks include both industry and other universities. The objective is to improve the cooperation both between universities and between academia and industry. The industrial partners support the initiative economically (mainly through personnel resources) and by providing their environments as potential study objects.
- *Technology transfer.* An aspect, which is closely related to the close relation with industry, is methods for technology transfer. These are important when we would like to transfer research results to practical use in industry. It is not enough to present new results, we must be able to show empirical evidence to succeed in technology transfer from academia to industry. Thus, we would like to stress that the research methods discussed above are one important means for technology transfer. Other important aspects are to recruit people to postgraduate studies, who have a background in industry. They could either work full time or part time as postgraduate students. Finally, another opportunity is to let postgraduate students spend part of their studies in industry in order to identify new research questions and to transfer there results so far.
- *Feedback to Master Programme.* The graduate courses in software engineering have been improved in a natural way, incorporating new research results, since the postgraduate students as part of their employment participate in graduate teaching. This is obviously important for the graduate courses, but it also provides excellent feedback to the postgraduate students. It is not until you are able to teach a subject that you really can claim that you know it in depth. Furthermore, the graduate students are always curious and have a number of questions concerning the subject, which provides important feedback to the postgraduate students.

The aspects listed are all important, and to highlight how we have instantiated some of them, we would like to provide a list of examples of postgraduate studies which are along the lines outlined in the items above.

Currently, we have tested six different strategies of managing the industrial relevance and the close contact with industry. At least one postgraduate student is, or has been, working according to each item presented below.

1. *Part time leave from company.* We have had one postgraduate student who was working part time with his studies and part time as a consultant in software engineering. This allowed him to obtain industrial experience which was useful in the research. The studies on the other hand gave him good insight into the state-of-art in software engineering, which was useful for him in his consultancy work. Persons of this category is thus formally employed part time by the university.
2. *Enroll people in industry.* A particular challenge in postgraduate studies is to enroll people who are working full time in industry, but is given the opportunity, by their employer, to conduct research (aimed at receiving a particular degree) as part of their normal work. This typically means that some of the work which should be conducted anyway should be of the type that it can be used within their postgraduate studies. The main difficulty in this situation is how to prioritize different types of work, and the problem is normally that the postgraduate studies have low priority from the company perspective. It is after all more important to have satisfied customers. It is, however, an interesting way of conducting postgraduate studies in software engineering as it really combines industrial work with postgraduate studies. This type of postgraduate studies requires strong commitment from the companies involved as the persons doing this type of studies are supposed to perform their research as part of their normal work.
3. *Case studies with funding.* A third category is when a company is interested in investigating a particular issue, and prepared to fund a research project at the university. In this situation, case studies are often natural. The research question is often coming from a particular problem that the company has observed. The research is normally conducted by observing through case studies, and then based on the observations changes are suggested and the outcome after the change is observed. Hopefully, the change was an improvement.
4. *Case studies with resources.* Another possibility is that funding for the postgraduate student is not obtained from a company, but the company is prepared to put in resources in terms of people and perhaps also fund any additional travel costs due to the study. This can be a rewarding way of conducting research when the research question is formulated at the university, but it is found interesting by an industrial partner. This is not directly a joint project as the work is conducted by people from the university, although the company finds the work so interesting that they support the work through providing resources that help with information gathering and also fund, for example, some travelling.
5. *Joint projects.* Joint projects between academia and industry are often a good way of working. This provides a natural channel for discussions and transfer of knowledge in both directions. A particular opportunity for this is within in the European Community where a number of projects are conducted across several countries and between academia and industry. The only major problem is that large projects tend to generate a great deal of overhead in terms of administration. In this particular case, we see that people from industry and academia work together in a project addressing a particular problem.
6. *Technology transfer project.* Finally, we would like to highlight the opportunity to conduct a

specific technology transfer project. This is in particular recommended when the postgraduate students have been pursuing their studies for a couple of years. In our system, it is quite natural to do this in close relation with finalising the Licentiate thesis. This means that the students can transfer and try to introduce some of their research results presented in their Licentiate thesis, and at the same time they identify drawbacks and unsolved research issues. These form a good basis for continuing the research studies and finalize their Ph.D. degrees.

These approaches have through experience been found to be important success factors in our postgraduate study programme in software engineering. It is, however, important to realize that the major impact on industry is through the graduate programme, where a large number of Master students are taking the courses and hence are exposed to software engineering. The broadest spreading of good ideas is probably achieved through integrating research results into the graduate study programme.

3.2: Master Programme

There are a number of important aspects that we consider when trying to achieve industrial relevance in software engineering at the Master level. These aspects include:

- *Curricula.* It is of course important to carefully select the topics that we teach, so that they reflect what industry needs. Later in this section we briefly describe the three software engineering courses given by the department.
- *Teaching methods.* We think it is vital to address the ways we teach, especially in software engineering. A problem-based teaching method with realistic scenarios of software development that mimic industrial best practice is an important element to achieve deeper understanding. We do not believe that a traditional “lectures from a book”-method alone will achieve the educational goals.
- *Industrial involvement.* If it is possible to have some degree of industrial involvement in the courses, e.g. through guest lecturers from industry (see strategy 6 below), we believe that the credibility of education is increased as the students see that people in industry struggles with the problems and solutions that we teach. Other forms of industrial collaboration in education are reported in [5, 6].

We have tested a number of strategies in our software engineering courses. These strategies are first described and then the software engineering courses at the Department are briefly described to provide the context in which the strategies are implemented.

1. *Research and education combined.* It has been found essential to involve the same people in both research and education. This includes both the academic staff and the postgraduate students. We are of the opinion that this way of working provides important feedback to the research in the same time as it ensures that the latest findings in software engineering are included in the courses. If some people just work with teaching, there is a risk that they will become isolated from new developments and from contacts with industry.
2. *Ph.D. students as teachers.* The involvement of postgraduate students in the graduate courses is important as it helps their research. It is also beneficial in terms of making it easier for the graduate students to relate to the lecturers, as they have quite recently taken the courses themselves. The postgraduate students are often highly motivated lecturers as they would like to make others interested in their area of research studies (if nobody is interested then what is the value of the research studies?). Furthermore, the presence of postgraduate students in the graduate courses facilitates recruiting of new Ph.D. students.

3. *Project courses.* Software engineering is about working in large projects developing software systems, hence projects in the education are an important ingredient. This includes both software development projects and projects more relating to investigating different issues in the area of software engineering. In particular, it is important to teach aspects of software development which normally arise when scaling up and to relate science to engineering [7].
4. *Master's theses in industry.* The Master's thesis work is often made in cooperation with industry. Industry provides the thesis questions and the students are supervised both by an industrial representative and one person from the academic staff. The actual topic of the thesis and questions to be investigated are formulated in cooperation between industry and the university. This type of Master's work ensures the industrial relevance, and provides an excellent basis for graduation and entering the industry after examination. It is up to the supervisor at the university to ensure that the educational objectives of the project are maintained when the work is performed in industry. The academic supervisor is also the person responsible for actually approving the Master's thesis, the industrial representatives have no voice in this decision.
5. *Industrially experienced teachers.* The objective of the software engineering courses is to teach an engineering approach to software development, imitating and teaching aspects which are crucial for large-scale industrial software development. Thus, it is beneficial if some of the lecturers, including the postgraduate students, have industrial experience from software development.
6. *Guest lecturers from industry.* To further emphasize the industrial aspect, we usually try to invite guest lecturers from industry, who can pinpoint and highlight some of the important aspects of software engineering based on industrial experience. These lecturers are mostly viewed as informative and stimulating by the students, as it highlights that the issues taught in the courses actually are needed and used in industry.

The above items are implemented into three courses at the Department. For example, the researchers and postgraduate students are teaching in the courses below. We try to bring in industrial guest lecturers and people with industrial experience to all three courses. The master theses are formulated within areas which are taught in the courses below in cooperation with industry as indicated above. The three courses provided in software engineering at the Department are:

- *Large-Scale Software Development* [8] (5 credit points) This course is the flagship among our software engineering courses. It is rated as one of the best courses within the Master programmes by the students. The course is taken yearly by 110-150 students. The objective of the course is to illustrate how large-scale software development can be carried out when a large number of people should work together to develop a software system. The students are divided into project groups of 14-19 students, and they should develop a number of telecommunication services using a well-defined process. At the end of the course, the services are executed on a private branch exchange and the students are able to phone each other using their own implemented services.
- *Software Engineering* [9] (4 credit points) This course provides an overview of software engineering, and also includes a project in which the students are faced with a software engineering problem. They are called upon to propose a solution based on information in relevant literature which they must find themselves. The project could, for example, be to propose how a fictitious company can implement a measurement programme. The project starts with the students specifying what they can deliver within a predetermined amount of hours. The course is normally read by 30-40 students.

- *The Personal Software Process (PSP)* [10] (6 credit points) The PSP was taught for the first time in the autumn of 1996. The objective is that the students should learn how to develop software systematically, and base their work on processes, process improvement and measurement. The focus is on aspects which are essential for large-scale software development, although they are practised on a personal level using the PSP. The course is read by 50-75 students.

4: Future directions

The issues discussed concerning graduate and postgraduate education are, from our point of view, important factors for successful software engineering education. They provide a good basis for educating software engineers which meet the requirements of industry. This does, however, not mean that the education cannot be further improved. In particular, we have a number of ideas of how to improve the postgraduate education.

The ideas concerning improvement of the postgraduate education include the following strategies that we plan to test in the future:

- *Case studies and experimentation.* We view empirical software engineering research as essential, and the objective is to increase our research into experimentation and case studies. In particular, the Department is a member of the International Software Engineering Research Network (ISERN, [11]). The intention at the Department is to perform both experiments in the university environment, and to work with industry in experimentation to increase the understanding of different software engineering methods, and hence allow for improvements. Moreover, the objective is to use case studies as a vehicle for software engineering research.
- *Software engineering shop* (primarily experimentation shop). To further emphasize the experimental approach to software engineering, and at the same time increase the interaction with industry, a software engineering shop is discussed. The objective of the shop is to allow companies to come with their questions, which can form the basis for stating hypotheses which can be evaluated using experiments. The intention is that the Department provides expertise in experimentation and that the experiments are carried out jointly with the industrial partner. Hopefully, this could lead to an increased interaction with companies that are not used to cooperation with the university. The companies should be able to use the shop without any explicit funding, although they are expected to participate in the experiment which implies that they have to set aside resources. The only requirement from the Department is that we are allowed to publish the results and use them in theses produced at the Department.
- *Industrial Licentiate programmes.* The Licentiate exam is by industry often viewed as a good degree, since it in 2 years provides deepened insight into the area without spending very long time on academic specialisation. The Licentiate students learn research methods which then can be successfully employed in an industrial context. Thus, it is often possible to encourage industry to enrol some interested individual in a Licentiate programme. This has been tried earlier but on a rather non-systematic way; the objective now is to apply for funding through a government fund and split the cost of the postgraduate studies between the fund and the industrial partner. The idea is that it should be possible to conduct studies either full time or part time. Thus, it should in particular be possible to perform research studies on part time and continue with more normal industrial work on part time. The objective is that the division should make both the industrial work and the postgraduate studies more efficient.

The graduate education has been improved recently; two of the courses described briefly above have been introduced into the graduate programmes during the latest three years. Thus, there is primarily a need to stabilize and make minor adjustments and improvements of the courses.

In our long-term plan for improving and extending the curricula at the graduate level, we have identified the following idea to be further pursued:

- *Virtual software enterprise*. In [12], experiences from teaching through real projects in a “virtual software enterprise” are described. We are currently working on a plan for introducing an extension of this idea in a 6 semester course, corresponding to 12 credit points, that will “employ” selected students for 3 years in a “company” that will deal with real software product development and maintenance. The first year is devoted to development work, the second year will focus on project management issues, and the final year will focus on strategic product planning and software enterprise management issues on an executive level.

Finally, it has to be remembered that the results from the Department are not only research results, but also a number of well-educated people in software engineering. Sometimes the emphasis is too much on research results, but the greatest impact on industry is probably through a good educational programme. This is one of the main reasons why we feel it is essential to have a close relationship between graduate education, postgraduate education and research.

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