How to train engineering students to cope with complexity in project management?

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Conference Key Areas: Education concepts specific for engineers; Learning formats specific for engineers; Specialized versus generic engineering education

Keywords: Complex Project, Unexpected Events Handling, Team Management

INTRODUCTION

Working in project mode is the daily routine for engineers and managers, whether simple contributors, in charge of a task or project managers themselves. This working mode usually leads to a rationalisation of the development cycle of products in order to stay competitive. Therefore, mastering of project management is an important skill which must be developed at the end of the engineers' training curriculum. From Peters [1]: *"Art and science of project management will become soon the very essence of training in management, of operational excellence and of added value."*

The project management domain is addressed at Telecom Bretagne, a high level French engineering school in information, communication and knowledge technologies; noticeably in our apprenticeship based curriculum. At the beginning of their final year, our students should already be capable of managing simple projects in their company or at school. However, these skills are not sufficient for students to be fully operational on large projects of high complexity and variability.

In order to prepare our students to grasp this type of project, a group of professors has designed a module for project management training where the complex dimension is a major factor. In this paper, after having defined the context of the training, we expose the problem we have to solve as teachers of project management. In the standard methods section, we explain the typical apprenticeship learning modes in project management and give evidence for their limitations. We then describe the method we have settled for exposing the students to complexity in projects. In the last chapter, we discuss the advantages of this process and explain the planned future improvements.

1 CONTEXT, PROBLEMS AND LEARNING OUTCOMES

A proportion of Telecom Bretagne students, who already hold a University Diploma in Telecommunication Technology or Computer Science, follows a three years apprenticeship based curriculum, with increasing periods in industry from two to six months. These students progressively take technical and managerial responsibilities. They develop a strong team spirit, want hard facts and have a high motivation for gaining competencies directly usable in industry. For the first two years, the students receive trainings, notably in project management and system engineering (functional analysis, risk and schedule management and project management planning). They also improve their knowledge in oral and written communication. The students are also taught basic management of simple projects. At the beginning of their curriculum, even if the students' host companies do not take the risk of involving students in complex projects, they expect such expertise to be available in the final year for the last six months project.

What distinguishes a complicated project from a complex one? A complicated project can be large but it is maintained under control if human and technical means are sufficient and if the customer's needs are well defined. A complex project contains elements whose interactions create uncertainties and human, technical and cultural variations. These strong interactions make the projects difficult to simulate and manage especially because of unexpected events handling. As defined by sociologist Edgar Morin [2], complexity is a mixing of several parameters which are mutually influenced. From [3], *"Complexity is also a new way of seeing the world. To get over the feeling of confusion and enable for them to see in the complexity not only a source of complexity but an opportunity for progress, the managers must renew their traditional way of addressing the problems and find the means for thinking their actions with and not against the complexity"*.

So, at the beginning of their final year, our students are able to analyse and satisfy clear requirements, even difficult ones. But, their employers want efficient contributors for managing complex projects whose ultimate goal is the satisfaction of the customer's needs [4]. How therefore can we expose our students to one of the biggest challenges for the companies and for the engineers which is to learn how to manage complexity [5]? Our school is the place where we can take the risk of putting the students before the challenge of complex projects.

We have settled what the learning outcomes of this new training are. At the end of the curriculum, the students must master the functional specification of the customer's needs; the process of managing a project by managing cost, quality, schedule and environment; the overall understanding of a complex problem and the analysis of its interactions; the elements of complexity linked to unexpected events and to human factors; team management in a multidisciplinary context. In chapter three, we present these different learning outcomes introduced in our new training.

2 STANDARD METHODS

Many approaches are used to teach project management: lectures, simulations [6], experiments or active learning [7, 8]. This teaching is based on a set of basic bricks identified as essential and standardized [9, 10] management tools. These include schedule, costs, quality and risk management. These bricks are often the basis of independent trainings. However, if these building blocks are pre-requisites, they are far from sufficient to understand the complexity of a real situation where all these principles interact with each other. Many authors note these limitations. In [11] we see: "*In our research, we have had difficulty finding educational providers, either REPs*[1] *or universities that prepare their project management students to deal with the increasing complexity that they will face in today's working environmen*t". They add: "*There appears to be a gap between what education providers are offering and what is needed to deal with projects in today's environment*". In [7], complexity is identified as a source of learning difficulty: "*The experience of one of the authors in teaching project management indicates that two of the largest challenges for students, especially those with little or no industry experience, are to understand the complexity of projects that the many causal relations create, and to appreciate at a visceral level the challenges of project management.*"
In addition, the tools and methods used for learning or for project management itself are very simplistic as the authors of [12] point out: "*Flexibility and adaptation need to be introduced into conventional, linear, project management models and tools*".
The lecture-based approaches may be well suited to the presentation of general principles for a large audience, like MOOC[2] as a new approach [13]. Simulation methods can be effective for virtual situations that focus on a particular point of project management [6]. Approaches by role-play or standard academic projects (clear objective, controlled context) are interesting to highlight some interactions among these many principles.
These methods form part of the basic techniques of project management. But they do not enough take into account the more or less explicit request from a client, the occurrence of many hazards or the human interaction of stakeholders. In addition, as indicated by [8], students feel very positive to work on a real project with real customer. Hence, to answer to [14] *"This level of training does not prepare people to deal with unexpected difficulties or unique situations. "Trained people" tend to fear change and be unable to adapt to unexpected situations and innovate new techniques and strategies",* our proposal is based on a real project, on intentional complex human organisation and on a prepared set of unexpected events.

3 THE METHODOLOGY FOR A COMPLEX PROJECT LEARNING MODULE

This complex project management training takes 63 hours spread over an effective period of twelve weeks. We have decided to use an active pedagogy based on apprenticeship by a technical engineering project as practising to get skills acquisition in project management [15]. The module is composed of few lectures and many of three hours group work lessons with a tutor.

3.1 A real technical project but outside of the students' field of skills

In 2012, the technical project was based on a technical and economical study for renewing the central heating system of Telecom Bretagne. As goal: the energy bill must be reduced as well as the carbon print of the school. The customer is the executive committee with the director and the manager of the technical services. The

[1] Research Experience Program
[2] Massive Open Online Course

budget is given for three years. The groups of students act as engineering companies replying to a call for projects; they must establish the technical solutions for a return on investment in fifteen years.
The choice of a subject out of their technical skills strongly destabilises the students. This destabilisation is positive for us because the temporary chaos generated by the subject has consequently forces the students to be concentrated more on their group organisation rather than on the technical study. This replies well to our main goal which is the learning of project management and not the achievement of a technical project. The choice of a subject out of their skills range stimulating complexity rose after two years of experiment. In fact, the first year, we proposed a subject in the centre of the students' skills field (optimisation of the school data network) and the apprenticeship was less efficient.
During the project, we introduce unexpected events with the aim of adding complexity (deliverable content or schedule, expert availability, unexpected audit about organisation methods). Even if this creates pressure on the students, our aim is to stimulate the groups' adaptability and to prevent their sleeping into a comfortable routine.
The subject must correspond to a credible project with a particularly well identified customer. The customer must be there and assume a clear customer-supplier relationship and show that he is waiting for practical results. For instance, the functional contract specification is signed by the customer after validation; it acts as an engagement contract for both partners. At the end of the project, the customer decides if the solutions are selected or not. We also think that it is better that the technical subject should be anchored in reality with ambitious deliverable which impacts the school life (i.e.: technical services, for professors or students…). This is an extra-motivation source for the students but this also involves quality constraints on the final result.

3.2 Numerous stakeholders with clearly separated roles

We decided to clearly split up the roles of the different stakeholders in four categories: (1) customer and his representatives, (2) methodology supervisors (MS), (3) technical experts and (4) project managers in activity. The customer (1) expresses his needs to the students. He validates the functional contract specification and evaluates the technical propositions. The MS (2), composed of professors of the school, are dedicated to the methodology of project management. They help the students and evaluate them. They supervise the groups' methods and the quality of organisation process. The MS also look after the communication process inside the group and toward the different stakeholders. Because the subject is out of the students' skills, we call on technical experts out of the school (3). They help the students to get a sufficient knowledge for performing a high quality answer to the customer. Project managers in the industry (4), alumni of the curriculum, come and provide evidence for their experience. Their position of alumni and their neutrality with the MS give them a strong credibility. This favours confrontation of ideas and exchange of recommendations. With them, the students understand that it could have some variations in the project management process according to the companies. The large number of stakeholders devoted to the project leads to complexity. This forces the students to well identify the actual stakeholders and to continuously adjust the content and the style of the exchanges.

3.3 Large groups and students with different cultures of company

The MS have decided to build large groups of students counting around 15 members to increase the complexity in the personal relationship. Mixed for at last two years,

the students know each other rather well. But, in this module, they must share the responsibilities and settle hierarchical relationship, noticeably for choosing the project manager. This can generate some strain, especially if the motivation is not uniform inside the group. The companies which take the students on half of the time have different organisation modes according to their size and their industrial domain. The apprentices use different tools and get project management skills with multiple approaches. So, the groups must compose with this complex multi-culturality for building up a uniform, connected and powerful group.

3.4 Groups in competition and with a controlled autonomy

Both groups work on the same technical project; so, and even if the MS do not formally ask for it, the groups work in competition for the delivery of the service. This produces an emulation which helps towards the students' deeper involvement in the project.

Our pedagogy is based on a controlled autonomy for the groups. After the students' distribution in two groups is performed by the MS, the students organise their groups as they wish with their own working methods. They chose the project manager, the different leadership roles and also the collaborative tools then want to use. This freedom is perceived by the students to be a source of complexity because they have important choices to make.

The human relationships often are the stumbling block of the projects. So the MS make a specialist available to the students. This specialist is an expert in group communication, team working, and conflict management. Some symbolic situations of failure seen by the MS can be used by the expert as work topics based on play-roles.

During the working class, a methodological tutor observes the group's behaviour and makes comments or recommendations spontaneously or if the students ask for feedback. At the end of the class, discussions of about thirty minutes are planned by the MS. During these discussions, group representatives describe only the methodological process used by the group (i. e. mode for the task assignment, risks, documentation and schedule management, communication inside and outside of the group). The MS give recommendations on weak aspects of the group organisation and this generates iterations in the processes to produce documents such as control panel and planning.

4 ANALYSIS AND DISCUSSION

This learning module completes the process of project management training by using a real situation where the students must reply to a real customer. We submit here some results and the main stakeholders' feedback.

4.1 Searching for the deepest student's involvement

In an unstable context (subject outside of the skills field, large size of the groups), the students quickly understood the necessity of a strong organisation. Both groups have established a traditional process management with a project manager and work-package leaders. The students have been involved in different ways but the project managers show the strongest involvement. One of the project manager decided to test the delegation and transfer of responsibility by "fair management" [16]. He motivated his members of staff by allowing them to define a personal work objective dedicated to the project (software skill development, a management or disciplinary theme like sustainable development or cost management). The work-package leaders were also able to try project management. Only those who were in the

technical tasks fulfilment have had less involvement in the management, they simply remained contributors and observers.

4.2 Skills gathered by the learners and their feedback

The students reinforced the skills used in former trainings and they acquired new ones: team management, negotiation capability, document management, handling of unexpected events and complexity, skills in relationship and conflict management.
A subject out of their skills field puts all students at the same level as they pointed it out: *"A subject totally new is a good thing because it requires soul-searching, fast adaptation and puts everybody on an equal footing for decision making"* (Student 1), and *"What was seen as a difficulty at the beginning became a source of trust proving that we are able to adapt ourselves in a domain a priori unknown"* (Group's report).
So complexity has been seen as well as an advantage (subject outside their skills field which makes them focused on the management) as an additional constraint (unexpected events) that the students have not necessarily identified before. For instance, they temporarily queried the capacity of the MS to professionally manage the training.
In the assessment, we see a very positive feedback from the students about the interest and usefulness of this training. Table 1 exhibits the results for the two consecutive years with a technical subject in the students' skills field in 2011 and outside their field in 2012.

Table 1. Quantitative results on the students' feedback performed at the end of the training

	2011: Rate of "Quite agree" + "Rather agree"	**2012**: Rate of "Quite agree" + "Rather agree"
I was interested and motivated by the training.	67%	100%
The quantity of personal work is suitable for the objectives of the module.	71%	35%
On the whole, this training will be helpful in a business.	85%	100%

One negative point is the students' quantity of work (average 91 hours on 2012 versus 30 hours on 2011) which leads the MS to adjust the workload demand in the future. The students' qualitative feedback shows this training as rewarding: *"This project (…) is probably the one which will affect me the most in my curriculum at Telecom Bretagne"* and *"At the end of the project, I am convinced that it is one of the most informative experiences during these three years".*

4.3 The different stakeholders' feeling

For the MS, the feedback came from the groups' observations, the different stakeholders' comments, the quality of deliverables and final oral presentations. The customer's profile and the credibility of the project lead to high quality level deliverables both for the technical and managerial points of view. The oral presentation of one group was of high quality with good perspective on the management process and convincing answers to the customer's need. In addition, the customer evaluated the technical deliverable as very satisfactory because the groups produced options that he had not himself anticipated. He committed himself

to implement a combination of both groups' offers. Given this different feedback, the MS are fully satisfied.
The professors must cope with a generation shock. As observers, they were surprised to observe students who rarely spoke during the group working lessons but who used collaborative tools and communicated with social networks. This must be a source of evolution in the next project management training sessions with students from the "Y generation" [17].
We want to favour the students' engagement and to fairly evaluate them, we established the following customised mark process: we give a collective mark to the group, then the students are free to individualise the mark inside the group with their own algorithm as long as the group average stays the same. Only one of the two groups has followed this proposal.

5 CONCLUSION

After two years of experiment, the complex project management learning module has turned out to be a very rich pedagogical experiment for the students, for the technical experts and for the methodology supervisors group.
The large group of students and the complexity of the project make it necessary for the groups to establish good processes for the organisation and for group working behaviour. The transformation under pressure of a set of students into a real project group, well organised and able to carry out a complex task is a spectacular and sometimes painful process due to the unavoidable frictions. In a similar way, the MS, the technical experts and the customer have to contribute at a level adapted to the demands made to the students.
As a summary, the realism aimed in this module has really been fruitful, much more than classical fictive type training can generate in a pure academic curriculum. All participants became strongly involved in their role. The students qualified this module as a striking experience in their learning curriculum, as a key element preparing them for the contribution to and/or management of projects in industry.
The project management process, the technical proposals and the oral presentations of the groups at the end of the module testify to a quality close to that seen in the professional context. Some technical suggestions were even selected by the customer. So, beyond the objectives of the acquisition of both technical skills and interpersonal skills in project mode, the technical output and the creativity shown by the students, exhibit beneficial consequences for all.

6 ACKNOWLEDGEMENTS

The authors would like to thank the management of Telecom Bretagne, especially P. Friedel, JP. Belleudy, H. Bouvier for interest and strong involvement in this training. A special thanks to K. Heggarty for his help in the paper translation.

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