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TEACHING ENGINEERING STUDENTS HOW TO DESIGN A PROOF-OF-CONCEPT: A WAY TO EXPERIENCE THE VALUE OF REFLECTIVE PRACTICES FOR ENGINEERS ?

**MAXIME THOMAS ; MARIAM LAFKIHI ; CAROLINE JOBIN, ERIC BALLOT ;
PASCAL LE MASSON ; BENOIT WEIL ;**

**Mines Paris, PSL University, Centre for management science (CGS), i3 UMR9217
CNRS, 75006 Paris, France**

ABSTRACT

Industrial companies expect engineers to take an external and critical look at their activities through reflexive practices. Recognising the criticality of reflexivity, Project Based Learning approaches include assignments for students to implement reflexive approaches on their projects. However, it remains unclear in the literature whether those assignments help the students experience the value of reflexive practices or if students consider them as academic exercises. In this concept paper, we present a new teaching module that intends to make students experience the value of reflexive practices for engineers.

In this module, an industrial partner asks a group of master engineering students to design and implement a Proof-of-Concept (POC) to help the company explore an innovation field. This eight-week project is mainly conducted within the company. Teachers act both as coaches through regular meetings and as experts through lectures focusing on specific engineering reasoning (statistics, modelling, simulation, design of experiments...) that are necessary to design a robust POC. At the end of the module, students present conclusions drawn from their POC to the company which explain to students the next steps envisioned from their contribution.

The module is two years old : so far, the authors supervised twelve students split into four industrial projects. Feedback for both companies and students were collected, as well as the lectures and the final presentations. Based on these, we conducted a preliminary analysis that suggests that students experience the value of reflexive practices for engineering work during the module.

1 INTRODUCTION : FOSTERING REFLEXIVE PRACTICES IN PROJECT-BASED-LEARNING

The ability to take an external and critical look at one's professional activity has been regarded for years as crucial for engineers. This ability was coined by Schon [1] under the term of reflexive practices¹. Recognising the criticality of reflexive practices, engineering education literature regularly calls for pedagogy that can encourage students to adopt a more reflexive attitude toward the work they are undertaking [3].

Fostering engineering students' reflexive attitude is often an objective of Project-Based Learning (thereafter PBL) approaches. PBL is an interesting approach as it confronts students with real open-ended problems where reflexive practices are particularly needed [1], [4]. However, reflexive practices are not naturally implemented, neither by students, nor by practising engineers. Therefore, teachers often impulse students' reflexive reasoning through specific assignments such as diaries, debates or reflexive questions on the journey followed during the project. These assignments often trigger original student reflections on topics he/she would have neglected otherwise [4].

Nevertheless, however good the reflection conducted by students, the question of whether they understood how to conduct reflexive practices remains open. Indeed, the literature highlights that conducting a complex engineering activity through PBL does not guarantee students' learning. Thus, attending a PBL design module is not enough as such to understand how to design [5].

More precisely, as reflexive attitudes in PBL are often driven by assignments given by teachers, one may wonder whether students really experience the value of reflexive practices for their future work. Indeed, the literature focuses more on assessing the reflexive skills mastered by students than assessing students' perception toward the value of reflexive practices [6]. Hence, our research question: how to make students experience the value of reflexive practices for an engineer in a Project-Based-Learning module ?

To answer this question, we conducted an exploratory case study based on a two-year-old teaching module of Mines Paris – PSL University, where students are asked by an industrial partner to design a Proof-of-Concept on an innovation subject.

Section 2 presents the methodology used to conduct the case study. Section 3 presents the teaching module of our case study. Section 4 explicits our findings. Section 5 displays our conclusive remarks on our research.

2 METHODOLOGY

We adopted an exploratory case study methodology to analyse how to make students experience the value of reflexive practices for engineers. The case chosen is the two-year-old module "Proof of Concept for a responsible industry" (thereafter POC module) in Mines Paris – PSL University, that we supervise. So far, we supervised 12 students split into 4 industrial

¹ Defining reflexive practices is a challenge for the literature and it is beyond our scope to provide a definitive answer. In this paper, reflexive practices include technical rationality, reflexion on action and reflexion in action as defined by Hatton and Smith [2]. We thank an anonymous reviewer for providing this reference.

projects. Our experience provides us with anecdotal evidence that students experienced the value of reflexive practices thanks to the POC module hence the choice of this module as a case study.

To conduct the case study, we collected as many evidence as possible to understand whether students and industrial partners highlight reflexive practices as valuable for engineers. We also gathered all the documents related to the POC module in order to identify the features of the module that helped students understand the value of reflexive practices for engineers. The data collected and the analytical approach are indicated in table 1.

Table 1. Data and data analysis of the case study

The evaluation of the POC module by the students takes place through a questionnaire students

Data	Analytical approach to the data	Data gathering
Final presentations and company reactions	Assess whether students rely on reflexive practices during final presentation	Recorded (n=4/4)
Evaluation and debriefing of the POC module by students	Assess whether students highlight reflexive practices as a key aspect of the module	Questionnaire (n=12/12) Field notes
Evaluation and debriefing of the POC module by the company	Assess whether companies highlight reflexive practices as a key aspect of the module	Questionnaire (n=1/4) Field notes
Documents related to the POC module (lectures, flyers...)	Identify features of the POC module that may help the students understand the value of reflexive practices	All documents

fill at the end of the module. The questionnaire is composed of several quantitative questions such as *“Did you like the project that you were entrusted with?”* and of several open questions such as *“What were your expectations at the beginning of the module?”* The issue of reflexive practices is never directly raised; however, some questions make room for students to provide answers related to reflexive practices, for example *“Do you think that the POC module enable a better comprehension of what is an engineer ?”*

The debriefing of the POC module with students is an informal one-hour debate on the module. We also met the students after the POC module, in particular when they explain it to undergraduates. We included the informal exchanges we had with them on this occasion as an element of the debriefing.

The evaluation of the POC module by the companies is conducted through a questionnaire composed of six open questions. Four questions relate to the work conducted by the students on their specific projects. The last two questions relate more to engineering reflexive practices: *“Do you think that a teaching module dedicated to the design of a POC is important for the training of an engineering student and why?”* and *“Do you think that a teaching module dedicated to the design of a POC could be relevant for working engineers and why?”*

Our analytical approach to the data is to uncover whether students or industrial partners mention that reflexive practices as a key aspect of the POC module. As we do not raise the question of reflexive practices, a mention of theses from students or from companies would be considered as very informing.

3 CASE

This section presents the “Proof of Concept for a responsible industry” module as it was structured in 2021 and 2022 in the master engineering programme at Mines Paris – PSL University. Section 3.1 presents the module from a content perspective and section 3.2 exemplifies one project that took place in 2022.

3.1 Presentation of the POC module from a content perspective

In the POC module, industrial partners entrust groups of engineering students to design and implement a Proof-of-Concept (POC) to explore a particular innovation field the company is interested in. Students are split into small groups, typically three students per group, and work for eight weeks on their project.

To select the projects, the teaching team look for three requirements. First, the subject has to be linked with a current innovation project within the company. Second, the company must be willing to conduct an experiment of some sort on the innovation field. Third, the company should agree to host the students as interns and make them meet experts of the innovation field explored.

At the end of their eight-week project, students are asked to present their work to the company and to provide two deliverables. First, they must issue a grounded recommendation to the company concerning what Proof Of Concept is to be implemented to explore the innovation field. Second, students are asked to present the analysis of a limited experiment they conducted during their project. Thus, they are put in the position to analyse the results of an experiment. Generally, they cannot analyse the POC they recommend due to time and resource constraints. At the end of the presentation, the industrial supervisor comments on the work of the students.

Before starting their eight-week project, students follow two introductory courses² : one on production and logistic management and one on innovation management.

During the eight-week project, students participate in three interrelated learning activities. First, they work on their project as interns in the company during two and a half day per week. Second, students attend lectures and associated tutorials for a total of four hours per week. Third, each group of students have a one-hour meeting per week with two academic tutors. The organisation of a week is given by table 2³

² These two courses are not specific to the POC module, they are open to other engineering students.

³ The shaded cells relates to slots dedicated to sport

Table 2. Organisation of a week during the POC Module

	Mo	Tu	We	Th	Fr
am	Project		Project	Coaching	Tutorial
pm	Project	Lecture	Project		Project

During the project, students are interns in the company: they work as an autonomous group that mimics an industrial project organisation. They receive supports both from their industrial supervisor that entrusted the project to them and from experts of the subject within the company.

The lectures focus on classical reasoning mobilised by engineers. In 2022, the lectures were the following : (i) Engineering Modelling ; (ii) Machine Learning ; (iii) Simulation ; (iv) Inferential Statistics ; (v) Design of Experiments ; (vi) Economic evaluation under uncertainty (vii) Risks associated with POC design. All the lectures are followed by a tutorial. The lectures and the tutorials are designed to show how classical pieces of engineering reasoning can be used to design a POC. Students are free to use or not these pieces of reasoning for their own project.

The coaching meeting is a favourable moment for students to present their work and to elaborate on what they need to do during the following week. The coaches are two academic tutors who belong to a lab where state-of-the-art research is conducted on POC and on POC design. Thus, the guidance of students is particularly well informed with insights on the usual pitfalls encountered by POC in industrial settings [7].

Presentation of the POC module with a project example : Improving glass wool stock management through image analysis. One of the 2022 subjects took place in an international company producing glass wool. The industrial setting of the subject was a leading plant of the company for the implementation of industry 4.0 technologies. In this plant, glass wool is stocked outside which leads to several stock management activities, one of which being regular inventories. The company has installed a 4D camera that is able to take pictures of the stock. The subject given to the student was : *“How to improve stock management thanks to image analysis algorithms?”*

During the project, students tested, on real data provided by the company, several image analysis algorithms, mainly to count glass wool pallets. During their final presentation, they presented their best performing algorithm as well as all the research paths possible for the company to improve the algorithm. After their final presentation, the industrial partner highlighted : *“The subject enable an exploration of the expectations we have on image analysis technologies for industrial purposes, subject on which we have a lot of progress to make [in our company]”*. (Industrial partner, Questionnaire, 2022).

4 RESULTS : EVIDENCE SUGGESTING THAT STUDENTS EXPERIENCE THE VALUE OF REFLEXIVE PRACTICES DURING THE POC MODULE

Several evidence suggests that students experience the value of reflexive practices for engineering work during the POC module. First, due to the innovative nature of the subject

they tackled, students were confronted to open-ended problems for which companies were unable to indicate what students should do. Several students highlighted that these situations made them realise that a specific reflexive approach had to be implemented. For example, one student stated that “we quickly realised that, in our company, they did not know how to solve the problem they gave us. We had to set up our own method” (Student, Debriefing, 2021.) The idea that the innovative nature of the projects was the root cause for the need of reflexive approaches is well shared among the students : “The exploratory nature of the subjects calls for a permanent critical approach on what we are doing” (Student, Questionnaire, 2021). Some students even link their reflexive attitude to engineering practices : “ I developed a critical approach to solve problems which now change the way I depict my missions [as an engineer]” (Student, questionnaire, 2022).

Second, students highlight that the weekly one-hour-long coaching sessions are moments to reflect upon their projects as well as key success factors. We received a lot of oral feedback from the students that indicate that coaching sessions were critical for the success of the project and 9 students out of 12 gave similar indications in the questionnaire. When digging into why students find the coaching session critical, the answers converge toward the following quote : “*Thanks to the project, we learn a lot of useful things as engineers and thanks to the coaching sessions we learn how to consider our subject with a different perspective*” (Student, Questionnaire, 2022). Therefore, it seems that students identify the coaching sessions as moments of reflection and found these moments useful for engineering work.

Third, the final presentations make students realise that other engineers conduct reflexive practices. Indeed, the final presentation is an opportunity for students to take part in discussions with other engineers. One example is provided in 2022 by a group that had to design a POC of a continuous inventory process. One of the main findings of the group was that there were different formulas that could be used to conduct such an inventory. As one of the students stated : “*Clearly, they [the company] had not realised that there were different formulas. The discussion [after the presentation] makes it clear that they need to reflect upon these formulas before implementing any continuous inventory process*” (Student 2022, debriefing)

Fourth, feedback from industrial partners also provides evidence that the POC module helps students realise the value of reflexive practices. According to the industrial partner, this understanding is achieved because the design of a POC leads the students to “*explicit the experiments conducted, the lessons learned and the recommendations derived from the experiments*” (Industrial Partner, Questionnaire, 2022). This feature of the POC module “*is probably even more interesting for engineers with 2-3 years of experiences of conducting industrial projects*” (Industrial Partner, Questionnaire, 2022).

Last but not least, through their final presentations, the students triggered reflexive practices of engineers of the company they were working with. For example, one presentation explicitly encourage the company to debate and agree on the mathematical formula that should be used to assess stock deviation (Students, Final Presentation, 2022). Industrial partners admitted that this reflection was of critical importance for the project they were pursuing. Thus, students experienced the value of reflexive practices as they witnessed their importance for working engineers.

Thus converging evidence suggests that the POC module allows the students to experience the value of reflexive practices for an engineer.

5 CONCLUDING REMARKS

In this concept paper, we conducted a preliminary analysis of a two-year-old teaching module where students are asked by an industrial partner to design a Proof-of-Concept on an innovation subject. Our aim was to strengthen our feeling that the POC module helps students understand the interest of reflexive approach. We therefore gathered several evidence indicating that students experience the value of reflexive practices [1] for engineering work.

As a concluding remark, we would like to highlight that the question of the features of the POC module that make students experience the value of reflexive practices still have to be investigated. To do so, we would like to relate the features of the POC module to engineering education literature to see whether such features are reported to be linked with reflexive practices.

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