PROJECT BASED LEARNING FOR MATHEMATICS IN GENERAL ENGINEERING CURRICULUM

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ABSTRACT

The National Engineering School of Tarbes (ENIT) is a French engineering school with a curriculum from undergraduate to graduate studies for general engineers. Curriculum ends by an equivalent Master degree in sciences. ENIT students are

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particularly involved into mechanical, civil, industrial engineering, material science and design of integrated systems.

From the first year of study, students tackle theoretical tools for engineers. Moreover, in a curriculum composed of several different disciplines, connections between scientific subjects may be difficult to weave. As a consequence, student activities for solving engineering problems were developed. The basic concept is to clearly illustrate how theoretical tools can be used in an activity linked to engineering and more generally to student life.

In addition, future engineers must be acquainted and trained to ethic values, especially those used in team work. During team working, honesty and benevolence are important core values to be encouraged as a basis of trust that has been identified as one of the cornerstones for performing teams. Consequently, the principle of team working for students was adopted and humanities are associated into the project to manage ethical and professional standards.

Thus, the chosen teaching activity is a project-based learning team work that addresses on the one hand application of integration and derivation to expression of needs of consumable supplies and notions around professional ethics on the other hands.

1 INTRODUCTION

1.1 General context

The National Engineering School of Tarbes (ENIT) is a French engineering school with a curriculum of 10 semesters training general engineers. Curriculum ends by an equivalent Master degree in sciences.

The ENIT's mission is to develop a publicly responsible, creative, competitive individual who is receptive to science, latest technologies and cultural values; to promote scientific progress, social and economic well-being. The school is attractive and is able to respond to the environmental challenges and has a great social importance to the national progress.

In this context, ENIT is asked about its competencies, specifically its ability to anticipate developments and drive its actions towards progress. Aware of the stakes, the logic of the development of ENIT has consisted not only of preparing its future engineers in line with the needs of companies, but also of taking into account permanently and supporting the reality of its economic environment. Therefore, ENIT has the ability to put in place new training corresponding to new professions and to social evolutions.

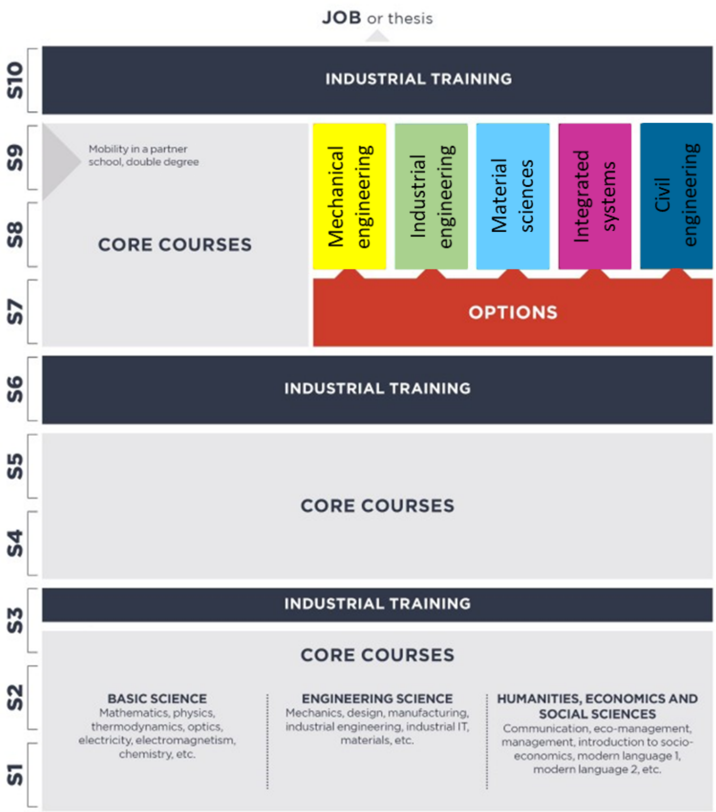

Fig. 1. ENIT's curriculum

ENIT mainly recruits students after high school of A-level. During the bachelor curriculum, the students follow scientific classes such as mathematics and physics but also classes of humanities, economics and social sciences. The part of engineering classes regarding classes of basic sciences increases each semester. During the master curriculum, the students follow core courses of engineering and also an option oriented to mechanical engineering, industrial engineering, civil engineering, material science or design of integrated systems. Moreover, as depicted in figure 1 where *Sx* means *Semester x*, industrial training lasts 2 semester and a half where autonomy of students is developed facing real industrial engineering projects.

1.2 Science and ethics as fundamentals for engineers

The engineers from ENIT can have technical and scientific jobs as well as management activities. The common point between all these jobs is the ability to model the world. Obviously, the model can be a mathematical one based on equations or logical links. But the model can also be an expression of links between people or communities using for example the ARDI (Actors, Resources, Dynamics and Interactions) co-construction method [1]. Based on this duality of models, the students are trained to mathematical modelling as well as humanities and social sciences from the beginning of their curriculum.

On the one hand, it is obvious that mathematics is a fundamental for modelling but is also a basic tool for physics as a common language to describe, solve and predict numerous phenomena. Moreover, in order to clearly apprehend the whole spectrum of applications, many bases are mandatory. That’s why mathematics is deeply taught at the beginning of the curriculum.

On the other hand, humanities are also a fundamental of engineering. Indeed, engineers are working in teams, they must communicate and argue all day long. Consequently, the students must be trained to team work, to imagine their roles in team [2] but also to take advantage of collective intelligence.

The paper describes how these fundamentals are introduced to the ENIT’s students. Section 2 deals with the activities proposed to incoming students in order to better understand the world and the job of engineers in its complexity. From these first steps, a project-based learning sequence is designed and described in section 3. Finally, conclusion and development opportunities that can be proposed are given in section 4.

2 ACTIVITIES FOR INCOMING STUDENTS IN UNDERGRADUATE STUDIES

2.1 Workshop: Engineering world in its complexity

The first activity proposed to incoming students lasts about 6 hours. It deals with an overview of the environment of engineers and its complexity. Two texts present a realistic situation that can occur in civil engineering companies. The first text exposes the case through the point of view of a client that has to deal with suppliers but also with the *make or buy* dilemma. The client expresses its supplying difficulties and the consequences to respect the delays facing unpredictable events such as the sanitary crisis or international war in countries providing raw materials. The second text outlines the same situation from the point of view of a team member of the supplier. Ethics is introduced with the moral dilemma between the duty regarding the client and the occupational health of co-workers as well as family considerations.

Even if the students are totally unaware of civil engineering, they are asked to work together to firstly model the case from the client's point of view and then to modify the model using the supplier's point of view. Here, the ARDI method is introduced through its application on the proposed example.

Moreover, at the beginning of the curriculum, incoming students don't know well each other. As a consequence, it becomes necessary to assume their own personality. The students naturally refer themselves as introvert or extroverted natures. In groups of 5 to 6 students, it is suggested to students to develop their active listening. Then, each student of the group can express its ideas directly or with the help of its colleagues.

At this stage, the advantages of collective intelligence are clearly underlined in order to introduce a new way of working together based on cooperation instead of competition. A reflective practice is initiated in this workshop with the aim of using and developing it all along the curriculum. The activity shows some students that are focussed on facts or key figures and some students more focussed on moral sensitivity and empathy [3].

Finally, the attention of students is oriented on the analysis of implicit and explicit parts of the texts that implies understanding and interpretation [4] leading to discussion and argue in the group.

2.2 Climate fresk

This activity is also proposed to incoming students and lasts about 4 hours. It is fully complementary with the one described in section 2.1. This workshop [5] is composed of different times where previous notions on team work are applied: ice breaker, puzzle time and collage, creative time, pitch, debate, talking about solutions.

The main goal is here to convince the students of taking into consideration emotions in their behaviour. Indeed, the managers and engineers often tossed out emotions from making decisions. However, the emotions should not be hidden in terms of quality of working lifetime. As a consequence, it seems necessary to better grasp the emotions especially linked to anxiety. The Plutchik's wheel of emotions [6] in figure 2 is here introduced.

Moreover, a particular focused is done to the time evolution of emotions regarding DABDA model [7]: Denial, Anger, Bargaining, Depression and Acceptance. It is required to move as fast as possible from denial or anger to acceptance. A 2D graph showing efficiency of action for climate regarding their personal or societal cost is established by students to demonstrate that a great change that seems difficult can be composed of individual changes that seem easier to realise.

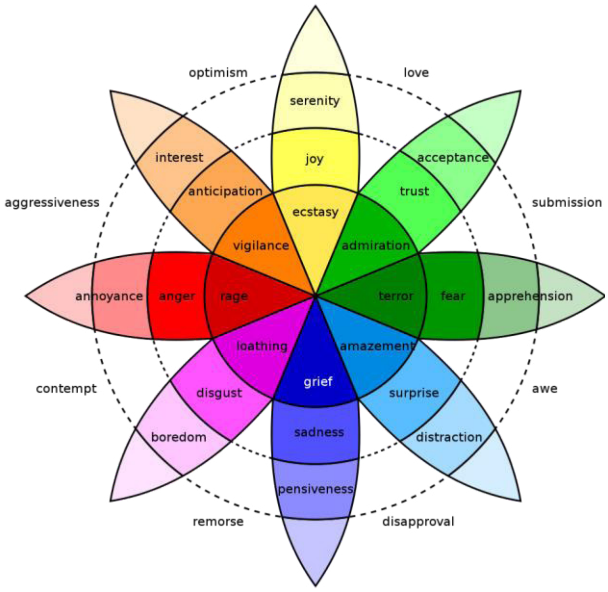

Fig. 2. Plutchik's wheel of emotions

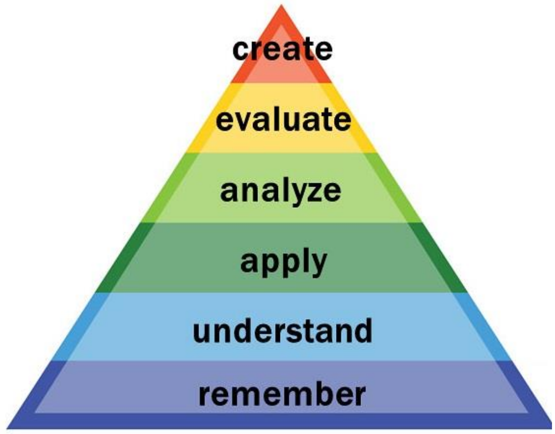

Fig. 3. Revised Bloom's taxonomy

2.3 Deconstruction of gender stereotype

Once the two previous workshops where working in teams is achieved, the behaviour of students is observed from the perspective of gender stereotypes [8]. First of all, the explicit gender stereotypes are underlined in courses where psychological aspects are addressed. The aim is to improve social and professional skills of students.

Moreover, through a reflective practice, implicit stereotypes are also decrypted. In order to uncouple behaviours from students, these ones are invited to participate to a forum theatre session where implied bad behaviours are caricatured in the external appearance of actors. It is proposed to the students to interact with the actors in order to try and check other behaviours.

These two activities last about 4 hours.

2.4 Project-based learning in mathematics

The last activity proposed to incoming students deals with the application of previous notions into a scientific context [9]. It lasts about 6 hours and can be split in two shorter activities. The students work in groups of 5 to 6 individuals.

In this activity, the main scientific goal is not to learn new knowledges but to improve some skills previously trained during high school courses. As incoming students come from different high school curriculums, it becomes necessary to define an activity about basic sciences. Regarding French curriculum, mathematics is a clear choice.

Moreover, regarding the previous activities, it is obvious that a project-based learning activity must be proposed to the students. Indeed, it allows them to apply previous skills such as active listening, cooperation, reflective practices, debating, talking about solutions and all of that with considering the analysis of any stereotypes and emotions during argue.

2.5 Individualized methodological support

All along the first year of study, the academic evolution of the students is closely followed by a team of teachers. This is achieved through the Individualized Methodological Support (IMS) program where the reflective practice is emphasised and guided depending on the students. A special focused is generally done on the working method of students and especially team work performed during revision process before exams.

A combination of previous activities and IMS program leads to a clear decrease of the number of students submitted to academic failure during the first year of studies.

3 DESIGN OF A PROJECT-BASED LEARNING SEQUENCE IN MATHEMATICS

3.1 Competency-based approach

Mathematics as basic science for engineers is often considered as a complex science by the students. They are mainly studied in the ENIT during bachelor curriculum during the two first years. Regarding the revised Bloom's taxonomy (see figure 3) [10], the students mainly *remember*, *understand* and *apply* their knowledges and skills during courses of mathematics.

However, during the master curriculum, the mathematics are applied in engineering as a tool that must be mastered by the students. It is then asked to the students to develop abilities in mathematics together with acquiring new knowledges and skills in engineering. This induces a clear frustration for the students.

As a consequence, it has been proposed to rethink the teaching of mathematics in the bachelor curriculum by defining new intended learning outcomes. Considering the activities for the incoming students, they become able to reach *analyse* and *evaluate* steps of the Bloom's taxonomy since the beginning of their curriculum in the application of mathematics. Obviously, this concept is firstly applied on knowledges and skills acquired during high school. In addition, work in teams is encouraged.

3.2 Scientific prerequisites

Considering the teaching of mathematics in high school, a problem-based learning sequence has to be defined where common knowledges and skills that can be turned to abilities during the proposed activity. Following a review of the curriculum in high school, knowledges and skills about mathematical analysis have been defined as the basis of the project especially derivative and integral calculus.

Moreover, during the high school, mathematical analysis is mainly developed through two main lines: *seek* and *model*. On the one hand, *seek* lies in analysing a situation, organising information and validating an approach. On the other hand, *model* is about converting a problem into mathematical language and validating a model.

From this overview, a pedagogical activity leading to work in team on a real problem has been built. It allows to analyse a situation - regarding the revised Bloom's taxonomy - i.e. to draw connections among ideas from different people, to listen, understand, examine and question their own perceptions and ideas comparing to each other's ones. It also allows to evaluate their work i.e. to argue and defend their point of view in a group and to present common conclusions. A feedback ends the activity with a constructive criticism phase between the different groups.

3.3 Ethics in project management

The proposed project-based learning sequence is also an opportunity to introduce the first steps of project management. As described in section 2.1, the students generally spilt in two categories: introvert and extroverted natures. At his stage, some roles in team work may be introduced. The nine Belbin team roles can be considered: three social roles (Resource investigator, Teamworker, Co-ordinator), three thinking roles (Plant, Monitor evaluator, Specialist) and three action roles (Shaper, Implementer, Complete finisher). However, the project is not sufficiently long to clearly define the nine previous roles in groups of 5 to 6 student through a given test. As a consequence, this part of the project is achieved in a reflective practice way. Indeed, the students are invited to note their own feeling about their role in the group and to think about it before ethics classes where the roles will be theoretically identified and where skills about their definition in a given group will be taught.

As a reflective practice, the main point lies in considering and analysing the advantage of cooperation and collective intelligence all along the project from the understanding of the problem, its modelling, its solving to the presentation and defence of a solution.

Some classical project management aspects are also introduced especially through the management of time. Therefore, it has been decided to propose two different projects of three hours each where time is firstly managed by teachers. They use a workflow where each phase is defined with a clear duration: presentation of the project (10 minutes), creation of groups (10 minutes), finding a solution (2 hours), writing a report (20 minutes), feedback (10 minutes).

In the phase of finding a solution, the students are invited to define their own workflow by evaluating the duration of main activities and tasks (analysing, modelling, arguing) and by monitoring their own planning and workload all along the project. Generally, the students begin the analysis of the problem using collective intelligence. Then, the finding of a solution starts with an autonomous thought. After several minutes, a confrontation of ideas is naturally initiate in the group. Finally, the writing of a report is done by a sum of individuals where the Belbin team roles begin to emerge.

3.4 Scientific details of the sequence

The subject of the project is defined as following: "A team of the ENIT's student office wants to paint the external surface of an old half-pipe. They request a subvention from the ENIT who grants them an amount of 300 euros. Their painting has an efficiency of $12m^2/L$ and a litre costs 21.17 euros (VAT included) for 0.5L or 77.17 euros (VAT included) for 2.5L." The question to answered is then: "Will they have enough money?".

The 3D model of the half pipe and a cross section are given in figures 4 and 5.

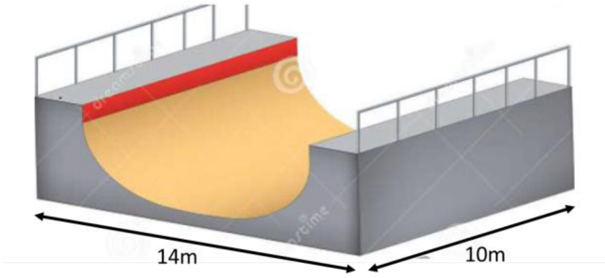

Fig. 4. 3D model

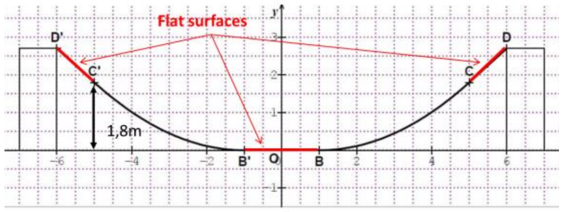

Fig. 5. Cross section

It has to be said that the half-pipe is symmetrical about y-axis. Moreover, the surface presents smooth connections at points C', B', B and C. Furthermore, surfaces from B' to C' and from B to C are defined by a parabola.

Using equations of parabola, linear equations and their derivatives, the students obtain a system of equations that must be solved to find the different parameters of the equations. Then a piecewise function can be defined to model the surface of the half-pipe. Finally, an integration must be performed to find the surface to be painted.

3.5 Evaluation of competencies

As it is the first project-based learning pedagogical activity proposed to incoming students, the evaluation of competencies does not lead to a grade.

First of all, a guided self-evaluation is performed by the students. There are asked to give a mark on a grading scale to 0 to 5 (0 means that competencies are totally unknown and 5 means that competencies are mastered) to several competencies in the fields of mathematics and humanities. Here are few examples of skills and abilities leading the definition of competencies: model a problem, calculate an area, calculate the derivative of a polynomial function, express an opinion in a group, exercise active listening, define my role in the group. This self-evaluation is compared before and after the project.

A collective evaluation of the competencies is then done by each group using a radar chart with six spokes: quality of the produced work, quality of the relationship with the teacher, quality of the analysis of the situation, involvement of each team member, organisation of the team and quality of the atmosphere in the group.

4 CONCLUSION AND DEVELOPMENT

4.1 Conclusion

In this paper, a set of activities proposed to incoming students in ENIT has been detailed. Working in teams and being a part of society have been used as a common link between activities. Moreover, collective intelligence and communication without tossing out emotions and empathy have been presented as ways of working efficiently in teams.

A focus has been made on a project-based learning sequence in mathematics involving humanities in the teaching. The project deals with presumed already acquired knowledges of the students during high school or previous activities. Mathematics is here considered as a heart activity in the wild field of engineering covered by the ENIT's students.

4.2 Evaluation and improvement

Some key performance indicators (KPI) can be defined for these activities. Obviously, KPI resulting from the evolution of the self-evaluation of competencies by the students must be studied. An increase in the acquisition or mastery of skills or abilities is a positive result.

Moreover, a global evaluation of teaching by students is performed at the end of each semester using an open dialogue with the head teacher but also with an anonymous survey with questions such as: "Do you feel that you are making progress in learning about your future profession as an engineer?" or "Do you have sufficient material conditions to work at school during courses?".

Depending on the evolution of KPIs, activities can be rethought, better organised, developed…

4.3 Development

It is planned to develop project-based learning all along the curriculum. Once the bases about humanities, project management and team work are acquired, it becomes possible to have more and more project-based learning sequences from understanding to evaluation levels in the revised Bloom's taxonomy. Moreover, year after year, the students become more and more autonomous and learning can be realised with a lower rate of coaching. Coaching is then reserved for launching the project and periodically monitor the progression of the students.

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