Training in Maintenance Engineering. Curricula proposal.

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***Abstract*—Industrial maintenance is a key activity to be considered in the productive process. Despite its importance, the specific studies to train highly qualified professionals in industrial maintenance are null or rare. Therefore, this paper suggests the topics and subjects to be included in an University Curricula to train Industrial Maintenance Engineers. This paper focuses on a practical feature of the training by presenting an already tested Project Based Learning (PBL) methodology where the local companies are involved. Results show the feasibility of the methodology and specially suggest the implementation of this methodology into the proposed *Maintenance Engineering Curricula*.**

I. Introduction

Machines and production systems become more and more complex since the first industrial revolution, combining different technologies like mechanics, electricity, electronics, hydraulics, and nowadays also informatics and telecommunications. From its beginning, engineering studies were focused to the design of technological systems and the subjects were oriented to a closed set of topics related with the main technology involved in the system. Therefore, mechanical engineers, electronic engineers, industrial engineers or telecommunications engineers among others, were trained.

In the real world, the production systems fail and must be repaired, but this evidence is seen in many organizations as an expense and not as an investment, reducing the efficiency of the maintenance work. Therefore, a *Maintenance Engineering Curricula* is of high interest to train, on the one side, technicians and engineers with interdisciplinary training in different technologies and in the management of the physical assets of the organizations, and on the other side to develop new research lines related to the maintenance.

The main goals of the maintenance tasks are:

- Get the highest availability of the production resources, by reducing the stop times due the corrective and preventive maintenance actions.
- Maximize the reduction of the arrangement costs of the production resources.
- Identify new methodologies and research lines to automatize and/or maximize the fulfillment of the previous goals.

In spite that there are a few maintenance engineering curricula in several Universities world-wide, there are not yet adequately propagated. Consequently, this paper highlights a curricula proposal to train specialized maintenance engineers and scientists, which should be capable to achieve the previously described goals, regardless of the productive sector where they would be applied.

The paper is organized as follows. This section introduced the motivation and the objectives of the paper by describing what are the guidelines in maintenance activities. Section II studies the enterprises requirements that justifies the training in maintenance engineering. Section III presents the suggested subjects and topics of the *Maintenance Engineering Curricula*. A Project Based Learning (PBL) methodology in cooperation with the business sector to improve the efficiency in teaching and the employability of the future engineers is presented in section IV. Section V shows the results acquired along the last 20 years in several subjects where the proposed methodology was implemented. Finally, Conclusions and Future work are highlighted in section VI, focused on the deployment of the curricula and the PBL methodology through the European Higher Education Area.

II. Requirements for the curricula

The different manufacturing processes imply different technologies. Therefore, the training of a maintenance engineer should begin with the generic basic subjects of an engineer, but also including the specific subjects related to the maintenance and a basic knowledge of the recent ICT technologies, to develop future strategies to identify the malfunctions and execute the preventive and corrective tasks related to it. Training in ICT technologies will help to include the new Industry 4.0, Industrial Internet of Things (IIoT), Big Data and Cloud based services challenges into the maintenance tasks, especially to help to identify, prevent and expand the knowledge base and therefore to reduce the maintenance or even to execute it automatically.

In addition, the risk systems, where a malfunction on the process or in the control system can endanger the whole installation or even the people around it or the nature environment, has to be under special consideration. Some of this kind of installations are the chemical or petrochemical industries, thermal generation of electric power (thermal and nuclear power plants), transportation industry (particularly passenger transport systems), food industry, dangerous machinery (presses or robotic work areas), tunnel ventilation systems, among others.

Maintenance are affected by the factors presented below:

- The reliability of the machinery or installation, due that the number of failures depends directly on them.

- The management of installation assets (human and technical resources) through their useful life.
- The risk level of the installation, specially in the corrective maintenance.
- The quality of the knowledge-base and the documentation of the installation, reducing the response times.
- The staff training.
- The company policy related with maintenance.

These factors does that the maintenance engineers have to be trained in reliability, maintainability, safety,

- Reliability, Maintainability and Safety.
- Physical asset and life-cycle cost analysis.
- Risk analysis
- Human resources and knowledge-base management.

Basic training and ICT technologies would be also mandatory, the first one to know the physical and Mathematical principles of the involved technologies and the second one to try to take advantage of the monitoring, management and communication capacities of the new informatics and telecommunication technologies.

On the other side, continuous maintenance training should be one of the strategic guidelines of the company, not considering maintenance as an expense, but as an investment to improve the product quality, the reliability and the competitiveness. In addition, it helps the staff to be motivated and fell a member of a highly qualified organization.

III. Curricular program

The proposed curricular program distinguishes between *basic engineering training* and *specific maintenance training*. It is framed into the European Higher Education Area (EHEA), also known as the Bologna Plan. A study plan, based on thematic areas, for a first cycle university degree (bachelor's degree) and a second cycle university degree (also known as master's degree) training is also proposed. The duration of each topic is presented in the European Credit Transfer System (ECTS), where 1 ECTS = 30 hours, including lectures and practical classes, private study, participation in seminars, projects and practical work and preparation examinations and assessment tests.

A. First-Cycle degree program proposal

The proposed study plan is planed for a workload of 240 ECTS credits that is the maximum permitted by the EHEA for the University First-Cycle. Table I shows the global distribution of ECTS credits by matter type. Tables II, III, IV and V suggests the contents for the basic training, technological training, specific maintenance training and maintenance tools respectively.

B. Second-cycle master program proposal

The master program is organized for 120 ECTS, that is the maximum allowed by the EHEA for the Second-cycle in University studies. The global organization is presented in table VI, developed in tables VII, VIII and IX.

TABLE I. (First-Cycle) ECTS credits by matter type

Matter type	**ECTS Credits**
Basic training	60
Technological training	90
Maintenance training	60
Maintenance tools	6
External practices	12
Final degree project	12
TOTAL	**240**

TABLE II. (First-Cycle) Basic training

Basic training (60 ECTS)
Calculus
Algebra
Physics
Chemistry
Technical drawing
Informatics
Statistics
Organization and management of companies
Industrial safety and hygiene (ISO 45001)
Risk analysis (IEC 63039, ISO 12100)
Human resources management

TABLE III. (First-Cycle) Technological training

Technological training (90 ECTS)
Technology of materials
Materials resistance
Thermodynamics
Fluid mechanics
Electrical engineering
Electric machines
Industrial electronics
Automatisms and control engineering
Environmental management (ISO 14000)
Thermal machines and engines
Manufacturing technologies
Industrial facilities
Sensors and actuators
Mechanic systems
Industrial communications
Measuring instruments

TABLE IV. (First-Cycle) Maintenance training

Maintenance training (60 ECTS)
Reliability (IEC 61703, IEC 61078)
Maintainability (EN 60706)
Availability
Safety (ISO 13849, IEC 62061, IEC 61508, IEC 61511, ISO 26262, IEC 61513)
Corrective Maintenance
Preventive Maintenance
Predictive Maintenance
Computerized maintenance management system (CMMS)
Root cause analysis (IEC 62740)
Condition based maintenance

TABLE V. (First-Cycle) Maintenance tools

Maintenance tools (6 ECTS)
Pareto Diagram
Ishikawa Diagram
Failure mode, effects, and criticality analysis (FMECA) (IEC60812)
Fault tree analysis (FTA) (IEC 61025)

TABLE VI. (SECOND-CYCLE) ECTS CREDITS BY MATTER TYPE

Matter type	ECTS Credits
Technological training	24
Maintenance training	36
Maintenance tools	18
External practices	12
Final Master project	30
TOTAL	**120**

TABLE VII. (SECOND-CYCLE) TECHNOLOGICAL TRAINING

Technological training (24 ECTS)
Biotechnology
Renewable energies
Industry 4.0

C. *Objectives for the future*

The productive systems are in continuous evolution, so even the evolution process should be taken into account for the training in maintenance. There are three aspects that should be incorporated transversally to the curricula:

- Normalization to manage the evolution process in a organized way. This includes quality controls (like the ISO 9000), nature environment control norms (like the ISO 14000) and safety and security norms.
- The knowledge-base management is a key factor to guarantee a positive evolution, so documentation processes have to be also transversally incorporated.
- Technology can be a loyal ally in maintenance tasks and its management. Therefore, the ICT technologies are a key factor to develop an adequate future for maintenance.

IV. IMPLEMENTATION METHODOLOGY

The basic and technical training methodologies have an important background in the engineering studies. However, the specific maintenance training may take advantage of the *Problem Based Learning* (PBL) methodology, already experienceded in an important number of Universities. This paper highlights an adaptation of the PBL technology to the *Maintenance Engineering Curricula* based on the involvement of the productive sector in the training process. Several engineering schools of the University of Vigo have more than 20 years experience in this kind of collaborations.

TABLE VIII. (SECOND-CYCLE) MAINTENANCE TRAINING

Maintenance training (36 ECTS)
Maintenance training plans
Quality Management System (ISO 9000)
Knowledge management
Asset Management (ISO 55000)
RCM
TPM

TABLE IX. (SECOND-CYCLE) MAINTENANCE TOOLS

Maintenance tools (18 ECTS)
Markov models (IEC 61165)
Petri nets (EN 62551)
Monte Carlo Simulation

A. *PBL Methodology*

Explainded in brief words, the PBL methodology consists on raising a technical problem by the teacher (or tutor) and developing the technical skills to solve the technical problem by the students.

The PBL methodology started 1969 in the Medicine Faculty of the McMaster University in Canada and in the School of Medicine of Case Western Reserve University (USA) [1]. Later, other Universities promoted the implementation of the PBL. Nowadays, it is one of the most promising training techniques in the First-Cycle curricula [2]. Several studies have been made related to its implementation and results, focused on the roles of the tutors, on the feelings of the students, on the most adequate student group size or the raised problems design, between others [3].

On the other side, PBL methodology is also based on the active and cooperative learning [4].This methodology has been applied in the training of engineering students, where the autonomous learning of the student is added to the group knowledge thanks to the commitment acquired by the student in the learning process [1]. However, the cooperative learning process has some difficult, so, again, the supervision of a tutor is required [5].

It should be considered that solving the problem is not the goal of the methodology, but to raise the training requirements that the future engineer will need to solve similar problems; and in addition, to take them and to use them in collaboration with the rest of the work group and the tutors. The raised problems have to be stimulating, so one of the problem solving results should be the motivation [6], [7].

B. *Application*

This implementation was generalized after the commissioning of the Bologna Plan, whereby the students do several activities like the problem solving, laboratory practices or tasks proposed by the teacher in a scheduled way [8]. But other main goal of the Bologna Plan is related with the employability of the students, and therefore, the involvement of the companies is a key factor in the training, mostly because of two reasons:

- The students integrates specific knowledge related with the productive sector in their training process, and
- the companies have the possibility to know and participate in the training topics of the students they will hire in the near future.

Therefore, a new method, focused on the involvement of the enterprises in the PBL is presented. The method was already tested internally for several subjects in engineering at the University of Vigo. It consists on choosing as raised problem to be solved a real problem suggested by a local company. This problem comes from the real needs of the company and not from the teacher. The raised problems have to be related with the subject under study, and they are coordinated between the company and the responsible teacher [9], [10]. The responsible teacher creates the academic framing of the problem and the evaluation weight.

The process to start this teaching and evaluation method consists on:

1) Search for companies that are willing to collaborate. The student has also the possibility to suggest a company to work with, if he has some kind of knowledge or relationship about the target company.
2) Once the company is selected, the teacher in collaboration with the specialized staff of the company identifies several problems that the company is willing to solve, related with the subject under evaluation.
3) The teacher, organizes and structures the work. He made the scheduling, the task divisions, the students groups organization, and the scope and documentation process.
    - The recommended size of the students groups are of 3 people, but in several occasions could be of 2 or 4 people.
    - The scheduling should be coherent with the academic course where the subject is included, including the documentation process.
    - The teacher has to guarantee that everybody in the group works in an equilibrated way.
    - Not all the works or problems identified in the company are homogeneous. That means that it is possible that some works requires that the students spend the most part of the time inside the company, or on the contrary, that the students have to meet the company only twice (to be presented to the specialized staff of the company who explains the problem, and to present the results to the staff).
    - Each team has to have a responsible person of the company, to be the person who the students contact every time they have to ask technical questions about the problem or to schedule a visit to the involved facilities.
4) Every work has to be documented in a technical report, to be presented to the teacher and to the technicians of the company.
5) Along the work period, the teacher monitors periodically the work progress. The monitoring method could be by meetings or other way of communications (e-mails, updating a report container or others). By our experience, a period of 15 days is good enough.

We have to consider that the proposed academical/technical works tries to solve a problem raised by the company, and that in some cases the solution provided may be of interest but in other cases the solution provided is not feasible or even there is no solution.

One of the most difficult parts is the evaluation methodology. Even if the raised problem is solved, it should not be the only criteria, because the different problems raised by the companies are very diverse and may not always have a solution or the solution is not easy. In this way, each work is completely independent of the other ones, and should be evaluated in a personalized way. Therefore, in addition to the results, it is especially valued:

- The methodology carried out.
- The initiative in the search of solutions.
- The rigor with which the conclusions were obtained.
- The final report and the presentation of the work.

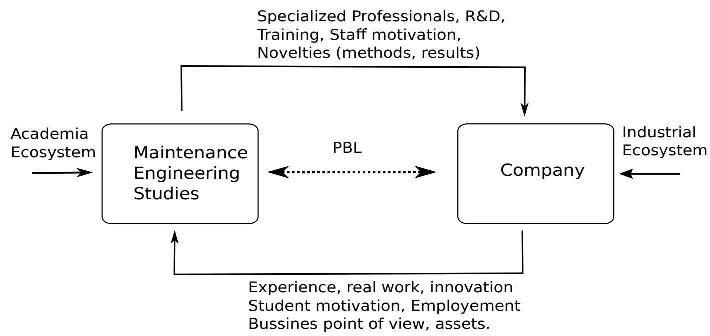

Fig. 1. Virtuous circle of the PBL methodology implemented in companies

V. RESULTS

This methodology began in 1998. Nowadays it is used in four subjects. Along these 20 years, the subjects involved were:

- *Reliability of Electronic Systems. RES*. This was an optional subject and was located in the 5th year of the degree in Telecommunications Engineering, specializing in Electronics. The content was related with reliability, maintainability, availability and security of electronic systems, or more specifically with RAMS (Reliability, Availability, Maintainability and Safety). It was a subject of 6 ECTS, having 45 hours of master lessons and 15 hours of laboratory. This subject ended in 2016. During these years, the 100% of the students chose to do the work and no one chose to do the exam.

- *Electronic Equipment Engineering. EEE*. It is an optional subject of 6 ECTS credits, which is taught in the 3rd year of the Degree in Telecommunications Technology and Electronics. This subject, although adapted to the Bologna plan, has a content quite similar to the previous Electronic Systems Reliability (RSE) qualification and constitutes the continuation of it in the new curriculum. This subject began to be taught in the 2012-13 academic year.

- *Implementation and Exploitation of Electronic Equipment (IEEE)*. It is a subject of 6 ECTS credits, which is taught in the 2nd year of the Master's degree in Telecommunications Engineering and Electronics specialty. In this subject the student dedicates 40 hours for the supervised works.

- *Advanced Design of Industrial Electronic Systems (ADIES)*. This is an optional subject that is taught in the first Industrial Engineering Master course at the School of Industrial Engineering and started to be taught in the course 2014-2015. It is a subject of 4.5

TABLE X. RESULTS FOR THE PROPOSED PBL METHOD

Subject	Start year	End year	Students enrolled	Participating students	Works finished
RES	1998-99	2015-16	240	240	95
IEEE	2012-13		99	81	27
ADIES	2014-15		12	10	5
ET	2013-14		106	93	33

ECTS credits in which the student spends 40 hours for supervised jobs.

- *Electronic Technology (ET)*]. This subject is optional and is taught in the 4th year of the Degree in Energy Engineering and specialty of Energy Efficiency, from the School of Mining and Energy Engineering. It has a teaching load of 6 ECTS credits, and it is the only subject of Electronics in this degree and began to be taught in the course 2013-2014. The works are frequently related to the selection of electronic equipment to solve specific problems related to energy efficiency, and proposed by the collaborating companies. In this subject the dedication for the tutored works is of 47 hours. Unlike the other subjects in this case students do not usually need to go to the company.

A. Students

Table X shows the number of students participating in the activity for each mentioned subject. Remembering that this activity is optional for the students, it can be seen that the vast majority of them chose the evaluation through work in collaboration with companies. On average, in all subjects, the percentage of students who pass the subject is greater than 98%. The cause originating that a small part of the students did not overcome the activity is because some unforeseen or poor personal planning prevented them from doing and/or finishing the activity.

Specifically in the subjects of RES and IEEE, some of the work done by the students was and is (in the case of IEEE) related to Maintenance.

B. Companies

In spite that several real problems raised by the local companies were solved by the students, or even some work results were suggested to be implemented, the main result of this PBL methodology was the creation of a virtuous circle between the academic and productive ecosystems (figure 1), and even the creation of dynamics in the academic framing of real problems by the responsible teachers.

VI. CONCLUSIONS AND FUTURE WORK

A new *Maintenance Engineering Curricula* is suggested in the frame of the European Higher Education Area, based on Elementary topics (like mathematics, physics and chemistry), on technical topics and on maintenance topics. Maintenance Engineering has to have an important practice component, and therefore a new preliminary procedure to carry out practices in companies is suggested based on the well-known PBL methodology. This procedure is tested and validated among the last 20 years in several subjects of Engineering Studies at the University of Vigo in Spain.

The methodology consists on stimulate the local companies to be a part of the curricula by raising real unsolved problems they have in its workload or work-process. The curricula offers part of the ECTS credits that the students have to spent in several subjects related to the work proposal, to carry out a solution to these problems. The work must always be done under the supervision of a teacher responsible for the subject.

Future work will focus on the integration of this methodology in a possible Maintenance Engineering Curricula. This is a preliminary work done in the framework of the European Project ‘Algerian National Laboratory for Maintenance Education” (Project No 586035-EPP-1-2017-1-DZ-EPPKA2-CBHE-JP); works are just beginning, therefore other curricular proposals and PBL methods (in collaboration with companies) are being collected; so new suggestions will be expected in future works.

VII. ACKNOWLEDGMENTS

This work has been partially supported by Spanish Science and Technology Ministry in the Project DPI2015-70031-R, cofinanced by the European Regional Development Fund (ERDF) and MINECO, and the European Project ‘Algerian National Laboratory for Maintenance Education” Project No 586035-EPP-1-2017-1-DZ-EPPKA2-CBHE-JP.

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