Innovative Methodologies to Teach Materials and Manufacturing Processes in Mechanical Engineering

J. Lino Alves, Teresa P. Duarte and A. T. Marques

Abstract This chapter discusses some methodologies implemented in teaching materials and manufacturing processes at the Department of Mechanical Engineering, of Faculty of Engineering of University of Porto, Portugal, that aim to keep mechanical engineering students motivated and strongly enrolled in classes. Practical classes are structured around experimental works where students have the opportunity to design and perform different experiments, do research using databases, training presentations, do technical reports and posters, and visits to industrial companies. Although the experimental works are very demanding and time consuming, they are extremely appreciated by the students, leading to great motivation for learning and an uncommon enrolment in the curricular units. This chapter presents the methodologies adopted in teaching metallic and non-metallic materials, considering international criteria for engineering students, and learning outcomes and competences. Finally, different cases studies of implementation of this project based learning methodology are presented. These classes contribute to acquire solid technical knowledge and simultaneously, development of soft skills that are extremely important and appreciated by the companies.

Keywords Teaching mechanical engineering · Materials · Manufacturing processes · Innovative methodologies · PBL

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1 Introduction

Teaching with success is a very demanding task, especially in present time, where the students have a continuous contact with the powerful tools of internet and media and nothing seems to surprise them. A rapid knowledge is obtained at the distance of a simple mouse click, independently of the region of the world where the learner is.

Nowadays, when students are admitted to the University, they have already a vast control of specific informatics tools, such as typing texts in word processer and making fancy power point presentations, and many of them are extremely fast at searching for an answer in the World Wide Web. However, when a deeper knowledge about the teaching subjects is required, difficulties start to appear and, essentially when some background about certain scientific principles is demanded, the problems are even bigger [1]. These are the main deficiencies that the authors detected on their students of the Integrated Master Course in Mechanical Engineering (MIEM) from the Department of Mechanical Engineering (DEMec) of the Faculty of Engineering of University of Porto (FEUP)—Portugal, during their classes about materials and manufacturing processes. The introduction of these subjects—materials and technological processes—with the detail that is presently taught is related to the type of mechanical engineers' necessities of the region and the country industrial tissue, and the global employment market. Due to the excellent technical and scientific training that this course (MIEM) provides, proved by the feed-back of national and international employers, in recent years MIEM had a very high demand index, within the panorama of Portuguese public higher education, being enhanced in the last two years, where:

2015—From 995 candidates (representing 2% of 48.306, the total national of public higher education), the number of candidates in 1st option was 374, with a ratio of MIEM candidates/number of slots in FEUP/MIEM equal to 6.2 [2].

2016—From 1059 candidates (representing 2.1% of 49.655), the number of candidates in 1st option was 356, with a ratio of MIEM candidates/number of slots in FEUP/MIEM equal to 6.6 [3].

Due to the increase in the number of students admitted in last years in MIEM/FEUP, and to meet the high demand expectations (Fig. 1) of Portuguese students that want to enter in the public higher education system, the number of experimental classes where students do experiences on their own were reduced.

Considering that and due to the present life style in our *digital society*, students' experimental skills and sensibility for "how to do it by doing" are continuously being reduced, and despite the *WWW* could be a possible milieu for discussion and virtual interaction, the reinforcement of the experimental activities and group work is an urgent need to "materialize" knowledge and experience.

Thus, in order to combat this trend, all the teachers and directors of MIEM, DEMec, and FEUP have been continuously changing its curricula, the teaching methodologies and evaluation system in order to have the courses with an international level, able to train young engineers with appropriate skills to the current demands of national and international companies that want to be globally competitive.

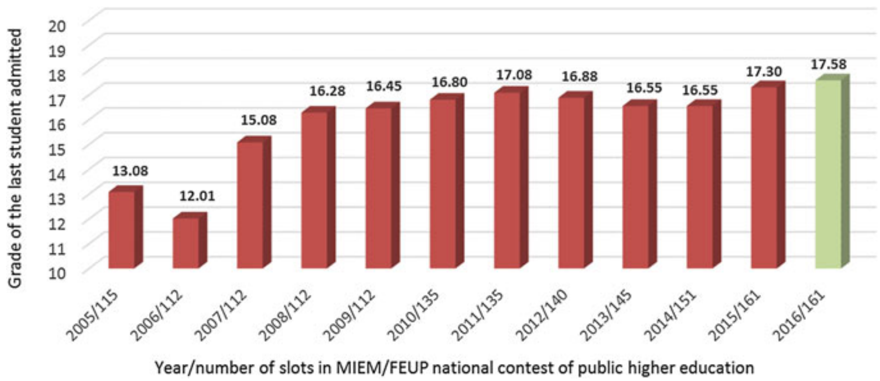


Fig. 1 Evolution along the years of number of slots in MIEM/FEUP and grade (in a scale of 20) of the last student admitted in the course as a result of the national contest for public higher education

In 2006 MIEM was configured according to the Bologna Process, in 2008 obtained the EUR-ACE Accreditation of European Engineering Programs, and in 2013 was ranked 28th in Europe and 92nd in the World in the NTU ranking (National Taiwan University) [4]. In 2016, the MIEM was again accredited by the EUR-ACE, however with some recommendations, being one of them, the increase of experimental classes, resulting from the interviews of the Evaluation Commission with students' leaders [5].

Besides that, FEUP/DEMec and MIEM participate actively in the International exchange programs for both IN and OUT students (Erasmus+, Mobile (Brazil, Latin America and Timor), Protocol with University of Maryland—Baltimore County (EUA), Program Almeida Garrett (Portugal), Projects Mobility Erasmus+ICM: International Credit Mobility, Mobile+2 Merging Voices, Net Magalhães—Program Smile) [6], and have a variety of collaborations with companies, research institutes and different schools worldwide. These exchanges and collaboration programs are an excellent way of implementing new methodologies in teaching, since by receiving students and teachers from other universities one can benefit from their experiences. Collaborations with companies allow the dissemination of the type of skills acquired by students, not only at a technical and scientific level, but also the soft skills that are developed in experimental classes with group works.

One of the main concerns of the mechanical engineering FEUP professors is the transmission of the best general competences CDIO (Conceive-Design-Implement-Operate) [7] and scientific knowledge, and also the development of skills that will be very helpful in the future active professional life.

According to Indicators and Standards that regulate higher education in Europe, the contents of the MIEM (in general), teaching and learning challenges and interaction and collaboration among teachers and students should contribute to the following CDIO skills number [7]:

- 1.2 nuclear knowledge in engineering;
- 1.3 advanced knowledge in engineering;
- 2.1 thinking and resolution of engineering problems;
- 2.2 experimentation and knowledge discovering;
- 2.4 personal skills and attitudes;
- 3.1 group work;
- 3.2 communication;
- 4.4 project.

Presently, the new evaluation system of engineering courses is also based on EUR-ACE skills [8] which for this course are (summary):

- 3.1 Knowledge and understanding—An in-depth knowledge and understanding of the principles of their branch of engineering;
- 3.2 Engineering analysis—The ability to solve problems that are unfamiliar, incompletely defined, and have competing specifications;
- 3.3 Engineering design—An ability to use their engineering judgment to work with complexity, technical uncertainty and incomplete information;
- 3.4 Investigations—The ability to identify, locate and obtain required data;
- 3.6 Transferable skills—Work and communicate effectively in national and international contexts.

The innovative teaching methodologies presented in this work are based on Project-Based Learning—PBL [9–11] and, in addition to the contents described in further sections, this type of evaluation also started to be implemented in 2010/11 in FEUP in the Specialization Course in Design and Product Development and currently in the Master Program of Product and Industrial Design [12–15].

Several researchers and teachers worldwide have also published their experiences using PBL: Panthalookaran and Binu [16], in Rajagiri School of Engineering and Technology, India, also tried something similar to nurture general management skills in their engineering students. Kostal, Mudrikova and Caganova [17], in Slovak University of Technology, Slovak Republic, improved their teaching methodologies through virtual laboratories, enforcing students' capacities to learn by their self-activity and self-responsibility and improving their communication skills. Peréz, García and López [18] in Polytechnic University of Madrid promoted the PBL in their Mechanical/Industrial Engineering courses. Frank, Lavy and Elata [9], in Technion, Israel, implemented the PBL through mini-projects that require the design and construction of devices that perform pre-defined tasks. Zhou [19] used the same type of work to teach manufacturing processes.

In Shamoon College of Engineering, Department of Mechanical Engineering, Beer-Sheva, Israel, Professor Iko Avital, streamlines a competition among students, to design and manufacture a small boat prototype to deliver food and drinks to the tourists in Dead Sea (Fig. 2). Student's teams and teaching staff participate enthusiastically in this project, and seek collaboration and advice from colleagues, professors and technicians.

Fig. 2 Annual dead sea competition of Shamoon College of Engineering, Israel

Meanwhile, some of our DEMec colleagues have also been doing great efforts to introduce these types of methodologies for a more effective knowledge transmission, which encourages extra efforts to keep improving and innovating in teaching methodologies in our materials and technological processes courses.

All these different PBL methodologies are focused on a higher students' responsibility and have a more experimental character with projects to produce or operate specific devices. Although we also have experimental work, a large emphasis is placed on searching scientific data and capacities to clear present ideas and participate in debates, soft skills fundamental to the professional success of young mechanical engineers.

This preoccupation with experimental work, is referred in many recent papers and largely discussed in conferences such as the annual International Conference EDUCON —Collaborative Learning, New Pedagogic Approaches in Engineering Education, organized by the IEEE (Institute of Electrical and Electronic Engineers) [20].

Considering the facts described in this introduction, two examples of classes about materials and processes will be presented, and the innovative methodologies adopted described in detail as well as the final main results achieved that contributed to the improvement of students skills.

2 Evolution of Teaching Methodologies in Materials Classes of MIEM

In the past (before 2006), teaching of Non Metallic and Metallic Materials in MIEM was performed in the classic way with theoretical and practical classes. In the theoretical classes of 1 h + 1 h per week (semester of 12 weeks) for around 130 students at the same time, being impossible to have a personalized knowledge about each student, the emphasis was on presenting the main subjects of the curricular units (CUs). In the practical classes (2 h for 25 students, maximum) students had the opportunity to carry on simple experiments. The final grade was composed by 20% for the reports of practical classes and the remaining 80% for the final exam.

In 2006, when the course was approved by Bologna Process, the teachers of Non Metallic Materials decided to accept the challenge of introducing in MIEM a curricular unit (CU) with the evaluation based on experimental works (PBL), discarding the exams. The classes were changed to just practical ones (with 4 works for ceramics and 3 for polymers) with the goal of giving the student a more responsible and proactive attitude, which is characterized by spending much more time at University/home studying the main topics taught in classes. Although the contents of the course remain the same, at the beginning of some classes each subject is briefly presented during 15–20 min maximum. After that, students have to answer the questions of the practical works using class facilities and complementary work done at University/home (the course has 6 ECTS—European Credit Transfer and Accumulation System [21] which corresponds to a total of 162 h (1 ECTS corresponds to 27 h work) of work during the semester, including classes, study, experimental and team work). This methodology was abandoned at the end of two academic years because of the large amount of time needed for teachers to properly assess students, in addition to the time spent in preparing and teaching classes and also requiring too much work time for students to the expected time for this CU.

After 2008, 2 reports for each part: ceramics and polymers, and answers to some handouts to be solved in class or at home are the only responsible items for the final grade obtained. This means that a deeper knowledge has to be obtained about the students from the discussions in all practical classes and continuous contact with the teachers, to obtain a more accurate and fair assessment.

After few years of using these methodologies in teaching and after analyzing the results obtained and comments from the students, the authors introduced in 2010/11 three innovations in order to address some detected deficiencies:

1. One class (2 h) in information literacy in FEUP library about how to use bibliographic databases. This session includes competences in searching in scientific databases (Compendex, Inspect, etc.), integral text, e-books, patents, dissertation and thesis and how to use the Endnote. This specific competences proved to be very helpful for all students, shortening their searching time and obtaining more valuable information and using it on the reports;
2. Seminar of electronic microscopy given by the Materials Centre of University of Porto [22], in order to give the students specific tools for microstructure analysis of all types of materials;
3. Introduction and use of CES Edupack software from GRANTA [23]. This software is very important to search information about materials and manufacturing processes and to relate properties with the specific production processes for all materials.

In relation to the CU of Metallic Materials, there were no changes since the implementation of the Bologna process in relation to the type of classes, and the theoretical classes were held for 1 h + 1 h per week and the practical classes of 2 h per week for groups of about 22–24 students. This CU has distributed evaluation (experimental work, preparation of written report, poster, presentation and oral defense—30%) with final exam (70%). In this CU, the innovation, described later, is to propose to the students more challenging experimental works, identification of metallic components, instead of experimental works about a specific heat treatment.

In the work presented here it is not intended to discuss the contents of the CUs, since in all the external evaluations to which MIEM has been submitted, the evaluation panels refer the fact that the subjects taught are adequate to the skills that a mechanical engineer should have.

This chapter presents innovative teaching methods where students are expected to acquire the contents of CUs by searching in high quality bibliographic databases, consulting technical books, viewing videos, or any other sources of information available nowadays.

The following sections describe the objectives of the assignments, all tasks performed by the students, and the evaluation processes.

3 Methodology

The experiments reported were developed in CUs related to the various materials available to the mechanical engineer more, in particular, metallic and non-metallic materials. It is intended that at the end of these CUs (together with a general CU of materials science taught in MIEM's first year) students acquire solid knowledges in this area, that can be used in CUs of manufacturing processes, design and others, and also to provide them with tools to solve all the challenges they will encounter in these subjects during their professional life.

3.1 Non Metallic Materials

Learning outcomes and competences

At the end of the semester (3rd year, 1st semester), the students should have acquired basic and advanced engineering knowledge about ceramics, polymers and polymers matrix composites, namely:

- Knowledge about the different ceramics, polymers and composites, used in the different brands of engineering, main applications and properties;
- Be able to understand the mechanical, optical, thermal and electrical properties of these materials;
- Be able to select the most suitable materials considering the desired application;
- Capacity to perform different types of experimental work to collect data, interpretation and relations with the learned subjects;
- Perform small experimental projects using the learned materials, namely materials selection and production processes;
- Capacities to collect and organize scientific information, using books, scientific papers, internet, databases, technical visits or interviews, elaboration of technical reports, posters and public oral discussions and presentations;

- Capacity to do practical team works, presentation and discussion of the results obtained [24].

In order to achieve the learning outcomes and competences, different experimental works have been proposed. In this work only two examples are presented, one in the area of ceramic materials and another in the area of polymeric and composite materials. Other experimental works already used in this CU are described in other publications [11, 25].

3.1.1 Ceramic Materials

Analysis and interpretation of a scientific paper

Objective:

Analysis, interpretation of a given scientific paper about ceramic materials and complementary search about the topic developed on the paper and elaboration of a report, a poster (A3 or A4), a presentation and public debate about the performed work.

The main challenge proposed to the students (groups of 2–3) is to do a report that contains the necessary information for the reader to take a decision:

> Consider that you are an employee in a company and that your boss asks you to study a subject and supply him/her with a report containing all the necessary state of art information to take a decision about adopting or modifying a technology/process in the company.

The scientific papers provided by the professors are, generally, all of the same year of publication, coming from reference journals about ceramic materials, with the same degree of difficulty of interpretation, identical number of pages and related to the CU contents. A guide, presented below, is also given to students, with detailed information on the preparation of this work.

Guide:

The reports should be quickly understood by the reader. Therefore they should:

- Be well presented (the subjects being well organized enhancing what is more important);
- Be well written and not contain spelling mistakes;
- Present the subjects obeying a scheme defined at the beginning. Thus, after the cover sheet, they should include the index showing the organization of the report;
- Use frequently graphics, tables, figures or others that turns the presentation appealing, easy to read and to understand the work performed;
- Indicate the main conclusions at the end;
- Identify the references, by names and dates, or numbers, on the text, figures, tables and graphics;
- Use SI Units.

The presentation of samples or parts/components of the studied materials, during the oral presentation, as well as personal initiatives to visit companies or interviews to specialists, related with the proposed topic will be graded positively.

Evaluation:

All the groups should deliver the report till the deadline (indicated at the beginning of semester) and supply on the 1st day of the oral presentations and debate a file containing the following elements:

- Presentation of the work;
- Poster;
- Report;
- Elements collected during visits or others.

Not obeying the deadline to deliver all the work elements will be negatively classified. All the reports presented by the students that contain parts from other reports will be graded with “0”.

The single use of internet sites as references will be classified very negatively. All the groups have to present in annex at least the three best scientific papers (copies) found about the studied topic (Warning: these papers should be used as references on the report). Do not forget that there are in the FEUP library, Databases, such as Compendex and the knowledge library: http://www.b-on.pt, where numerous papers can be found.

Detailed instructions about reports structure:

The basic structure of the reports (to be adapted for each particular paper) should be the following:

- Cover sheet: Authors of the report (complete names), local, period of the work and due date, subject and course, work title, number of the group and class, reference to supervisors and main collaborators.
- Contents: Include page numbers and all the detailed titles indicated along the work.
- Summary and Objectives: The objectives and working methods employed should be clearly indicated.
- State of Art: Comprehension and discussion of the following aspects (adapted according to each paper subject and relations with the contents of the curricular unit):
  - Typical chemical composition, type of chemical bonds, structure, etc.;
  - Powder manufacturing processes;
  - Physical and mechanical properties, or others;
  - Processing (manufacturing processes for parts and components);
  - Applications (practical examples in different areas);
  - Future and new challenges;
  - Other elements that seem interesting (for instance, recycling possibilities).

- Conclusions: Present the main conclusions in a clear synthetic way.
- Future work suggested and criticisms: when justified, the difficulties found and suggestions concerning performing future work, working methods, topics, etc., should be indicated.
- References: The incorrect indication of the references penalizes significantly the work. Each reference or paper should be indicated in brackets along the text, using the last name of the first author and publication date, or alternatively by a number. At the end of the work, each author cited will have the complete specification of the reference, including:

Author(s), title, editor (or journal where the article is included), data, local of edition and pages

In case the reference was done by two or more authors the abbreviation et al. can be used in the text, but at the end all the authors have to be referred.

Example:

Reference during the text:

(Duarte et al. 2008) or [1]

Reference in the bibliographic references:

[Duarte et al. 2008] Teresa P. Duarte, Rui J. Neto, Rui Félix, F. Jorge Lino, "Optimization of Ceramic Shells for Contact with Reactive Alloys", Trans Tech Publications, pp. 157–161 (2008);

or

Teresa P. Duarte, Rui J. Neto, Rui Félix, F. Jorge Lino, "Optimization of Ceramic Shells for Contact with Reactive Alloys", Trans Tech Publications, pp. 157–161 (2008) [1].

Presentation and Oral Debate:

The schedule of oral presentation of the work is defined at the beginning of the semester. The maximum time for the presentation is 8 min for each group (exceeding this time has a penalty) followed by a debate (around one hour) with all the students that did the same work (see Fig. 3).

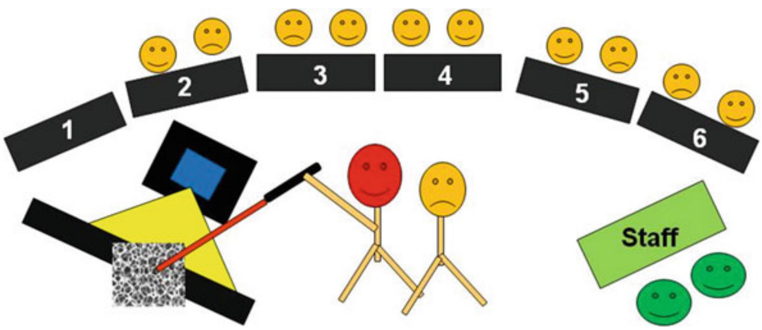


Fig. 3 Schematic of the debate

The evaluation of each group element is based on the following:

- Time used during the presentation;
- Presentation structure;
- Knowledge of the subject, capacity of making a presentation and answering questions about it.

The questions of other group colleagues and the teaching staff are helpful to enhance the debate. The performance of each student will be evaluated by the teachers of the curricular unit and by the students.

Poster:

The poster is evaluated considering the inclusion of the following elements:

Design; Subject title; Course; Year; Objectives; Introduction; Work done; Conclusions; Future work; Photo of the groups elements; Place of the work; and other elements considered relevant.

In order to encourage students to produce high quality posters both in terms of content and design, in the last 4 academic years (since 2013/2014), teachers have decided to launch a competition and to award a diploma the 3 best posters each year which are displayed in the DEMec's standpoint (Fig. 4) in the following two academic years, and serve as an example to the students of MIEM.

Figure 5 shows two posters of this subject; poster (a) is considered a good one, while poster (b) had a lower grade (it does not have the period of the work, course, objectives and conclusions, does not explain the topic of the paper, no captions and has a poor design).

Grade:

The final grade is obtained by the evaluation of three main items:

1. Report (11/20):
   Cover sheet (1/11); Contents (0.5/11); Summary and objectives (0.5/11); State of Art (4/11); Conclusions (1/11); Future, criticisms and annex (0.5/11); References (1/11); The three best scientific papers and their use on the report (2/11); Design of the report (0.5/11);

Fig. 4 Posters' displayed in DEMec aisle and classroom

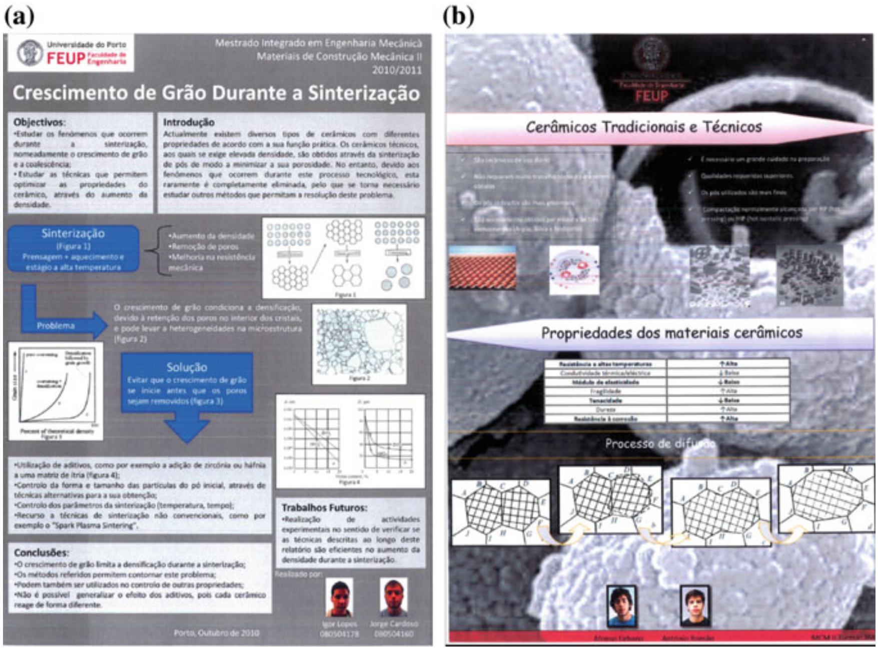


Fig. 5 Posters of the work **a** poster with a good grade and **b** poster with lower final grade

2. Poster (3/20)
3. Oral presentation and debate (6/20):
   Oral presentation (3/20); Debate (3/20).

In the following, the papers from International Journal of Applied Ceramic Technology provided to students in the 2016/2017 academic year are presented, where one can see that the covered topics to be studied are actual and pertinent.

1. Robert Gmeiner, Gerald Mitteramskogler, and Jurgen Stampfl, Aldo R. Boccaccini, "Stereolithographic Ceramic Manufacturing of High Strength", Int. J. Appl. Ceram. Technol., 12 [1] 38–45 (2015).
2. Uwe Scheithauer, Eric Schwarzer, Hans-Jurgen Richter, and Tassilo Moritz, "Thermoplastic 3D Printing—An Additive Manufacturing Method for Producing Dense Ceramics", Int. J. Appl. Ceram. Technol., 12 [1] 26–31 (2015).
3. Jie Yin, Zhaoquan Zhang, Zhengren Huang, Hui Zhang, Yongjie Yan, Xuejian Liu, Yan Liu, and Dongliang Jiang, "Aqueous Gelcasting and Pressureless Sintering of Zirconium Diboride Ceramics", Int. J. Appl. Ceram. Technol., 11 [6] 1039–1044 (2014).
4. Guosheng Xu, Tomohiko Yamakami, Tomohiro Yamaguchi, Morinobu Endo, and Seiichi Taruta, Isao Kubo, "Pressureless Sintering of Carbon Nanofibre/SiC Composites and Their Properties", Int. J. Appl. Ceram. Technol., 11 [2] 280–288 (2014).

5. Michael C. Tucker, Jay Tu, "Ceramic Coatings and Glass Additives for Improved SiC Based Filters for Molten Iron Filtration", Int. J. Appl. Ceram. Technol., 11 [1] 118–124 (2014).
6. Amnon Rothman, Sergey Kalabukhov, Nataliya Sverdlov, Moshe P. Dariel, and Nahum Frage, "The Effect of Grain Size on the Mechanical and Optical Properties of Spark Plasma Sintering-Processed Magnesium Aluminate Spinel $MgAl_2O_4$" Int. J. Appl. Ceram. Technol., 11 [1] 146–153 (2014).
7. Ramanathan Papitha, Madireddy Buchi Suresh, and Roy Johnson, Das Dibakar, "High-Temperature Flexural Strength and Thermal Stability of Near Zero Expanding doped Aluminum Titanate Ceramics for Diesel Particulate Filters Applications", Int. J. Appl. Ceram. Technol., 11 [4] 773–782 (2014).
8. Preeti Bajpai and Parag Bhargava, "Effect of Heat Treatment Schedules and Glass Powder Particle Size on Glass Infiltration in Porous Alumina Preforms", Int. J. Appl. Ceram. Technol., 11 [3] 543–549 (2014).

The evaluation of this work has not always been the same in all the academic years, having varied according to the total number of students, with the analysis of the results obtained in each year and also with improvements proposed by the students.

In the last three academic years, the debate and oral presentations were no longer held due to the high number of students enrolled in this CU as a result of the increase in the number of students joining the MIEM (Fig. 1). The evaluation of this work was carried out only by the delivery of a written report, analyzed with much more rigor and giving a great deal of relevance and quotation to the capacity of synthesis, ability to present other scientific works carried out in the same area of knowledge and great exigency in the quality and presentation of the bibliographic references used to make the report.

The ability to perform oral presentations, debates and posters is evaluated in another experimental work proposed in the part of ceramic materials with the title: Production of ceramic components.

Results Analysis

Reports:

The analysis of the reports delivered by the students has shown that they can produce a very well structured report, with very high graphical quality (cover sheet, figures and tables, typing font and layout of the pages). This means that in general the reports are pleasant to read and the main conclusions and important data are very easily and quickly obtained.

The weak points detected in the reports are:

- Many students still have difficulties in indicating the sources of the data, figures and tables used on the report, although very precise instructions were supplied to them (this has been improving over the years);

- Some did not understand the correct way to indicate the references along the text although they introduce the references at the end in a correct and complete way;
- There is still a tendency to use as references, a considerable number of websites. Although this is not bad, because a lot of useful information can be obtained, it is not enough for engineering students;
- The great majority selected the three papers that they considered the most important and included them in the Annex, but they did not use the concepts/ideas contained in the papers in the report. This means that this capacity to extract the most important data (synthesis capacity) from a subject that is studied and explained in detail is still a lack in students' capacities.
- Some of them complain about the difficulties in understanding technical English;
- Most of the students focus some innovative tendencies for the future in the subject presented in the paper, but many of them forget to check if the authors have published any other papers after the current one. This is a very important issue, considering that in some years, not all the papers submitted to the groups were from the same year, and many innovations could occur after the supplied paper.

Posters:

In general, students design posters in accordance with the supplied instructions. Some had a lower grade because they do not have the period of the work, course, objectives and conclusions, do not explain the topic of the paper, do not contain captions and has a poor design (Fig. 5).

Oral presentation and debate:

- Students are still not very comfortable with this type of evaluation, and many of them tend to almost not raise questions to the colleagues, because they fill inhibited and are afraid of what the colleagues can think about them;
- Some students are very active and participate intensively, but many times they just talk about generalities, when the teaching team ask about more detailed aspects of the work, and specially topics where it is necessary to relate the things that they read with the contents of the CU, they have serious difficulties;
- Although students have to evaluate other students' presentations and discussions, they tend to give very high grades to all of them and not distinguish the ones that really know the contents of the CU. However, this has been corrected recently with the amount of points that the students can distribute in their grading.

From all the work performed by the students, one can summarize the following points:

- Some difficulties still persist to transmit to the students groups the rigor of the assignment and their responsibility in creating the necessary conditions to independently conduct the work to reach the course goals.
- After some years of implementation of this type of work, we figure out that students are improving and start to be more familiar with this type of challenges. This is the only class, during their Integrated Master's Course in Mechanical Engineering, where they are confronted with this type of continuous evaluation.

We asked some students to give their opinion about this practical work, and the main points can be summarized as:

- Difficulties in reading and understanding technical English, but in the end they considered that they reached significant improvement. This is the main difficulty and we are strongly convinced that this is the reason why they do not include more scientific papers information on the reports;
- Short period of time to perform the work, considering the requests that they had at the same time for other CU;
- Difficulties in collecting information about more technical aspects, due to not finding the correct papers and also because some of the papers that they considered interesting, based on the available abstracts, were not of free access and signed by the school library;
- Not many books available about ceramics;
- They liked the challenge for the deep study of the ceramic topics, considered the supplied papers interesting, learned a lot and should even have more time to better study the subject;
- The work contributed to their synthesis capacity, and a systematic way to study a subject.
- An excellent challenge placed in the curricular plan in the middle of the course and that allows to prepare the way in which a master's thesis must be elaborated.

After 9 years of schooling to challenge the 3rd year students of the MIEM with this work, some changes have been made, some by students' suggestions, others because now there are more students than at the beginning of this pedagogical experience (Fig. 1). As an example, it was decided in the next academic year (2017/18) to change some items of the guide given to the students, namely: definition of the maximum number of pages that the reports must have (development of synthesis capacity), request the presentation of the summary of the scientific paper delivered to each group in the form of a schematic, with a maximum of two pages and elaboration of a mind map with the main topics of the article and that indicates the main questions that it raises, in order to perceive more easily the strategy followed by each group.

3.1.2 Polymers and Composites

Polymers and composite materials of polymeric matrix: from base science to engineering applications

Objective:

Perform a bibliographic study (monograph) of the subject aiming the learning of polymers and composite materials of polymer matrix, from the chemical part, to their mechanical behavior, transformation processes and applications.

To accomplish the above, students (in groups of 2–3) should do research on technical-scientific articles and bring them to the discussion in class. This should be done through oral presentations in class, report and final presentation (5 min) followed by a final discussion. In the end of semester, they should elaborate a monograph on the subject, taking into account all the suggestions and indications given by teachers and colleagues during preliminary presentations.

Students should follow the same instructions given in the work on ceramic materials (Analysis and discussion of a scientific paper) as regards the preparation of reports and correct presentation of bibliographic references. It is intended that every year the subjects were different, up-to-date and suggestions from students who demonstrate particular interest by a certain subject that fits the contents of the CU, are always accepted.

As an example, some of the themes given in 2016/2017 are indicated below:

1. Methodology for design of moulds in polymeric matrix composites
2. Methodology for design of dies in polymeric matrix composites
3. Characterization of polymers and polymeric matrix composites for bicycle wheels/tyres
4. Characterization of polymers and polymeric matrix composites for car wheels/tyres
5. Processing of polymers and polymeric matrix composites for Formula 1 helmets
6. Polymers and polymeric matrix composites for sustainable development: waste-for-life
7. Design of musical instruments in polymers and polymeric matrix composites
8. Selection of polymers and polymeric matrix composites for pneumatic circuits
9. Selection of polymers and polymeric matrix composites for hydraulic circuits
10. Methodology of short and long-term design of pressure vessels made with polymers and polymeric matrix composites
11. Water assisted injection moulding: process simulation
12. Injection moulding of polymeric matrix composites: process simulation
13. Thermoforming/“stamping” of polymers and polymeric matrix composites: process simulation
14. Extrusion of polymers and polymeric matrix composites: process simulation

15. Hot plate press of polymers and polymeric matrix composites: process simulation
16. Polymers and polymeric matrix composites for energy generation (including polymeric trees and plants)
17. Selection of polymers and polymeric matrix composites for aerospace and aeronautic industries
18. Polymers and polymeric matrix composites for high temperatures: raw materials, processing and characterization
19. Polymers and polymeric matrix composites for adaptive structures: applications, characterization, processing
20. Recycling of polymers: recycle, reprocess, reuse
21. Recycling of polymeric matrix composites: recycle, reprocess, reuse
22. Processing of polymers and polymeric matrix composites for electric and electronic industries
23. Conductive polymers and polymeric matrix composites: how to enhance electrical and thermal conductivity
24. Manufacture of vessels/tanks in polymers and polymeric matrix composites: process simulation
25. Natural polymers and polymeric matrix composites: origin, processing, characterization, end of life
26. Biomimetic applied to polymer development
27. Biomimetic applied to the development of polymeric matrix composites
28. Challenges for polymers and polymeric matrix composites in the shoe industry
29. Project specificities with polymers and polymeric matrix composites
30. Selection of polymers and polymeric matrix composites for offshore wind energy
31. Polymers and polymeric matrix composites for "Additive manufacturing": raw materials, processing, applications
32. Polymers and polymeric matrix composites for 3D "printing": raw materials, processing, applications
33. Cold press of polymers and polymeric matrix composites: process simulation
34. Prediction of long-term behaviour of polymers and polymeric matrix composites
35. Fatigue behaviour of polymers and polymeric matrix composites
36. Creep and stress relaxation of polymers and polymeric matrix composites
37. Stress corrosion of polymers
38. Toughness of polymers and polymeric matrix composites
39. Life cycle analysis of polymers and polymeric matrix composites
40. Permeability of gases in polymers and polymeric matrix composites
41. Influence of humidity in the short and long-term mechanical behaviour of polymers and polymeric matrix composites
42. Influence of temperature in the short and long-term mechanical behaviour of polymers and polymeric matrix composites

43. Influence of aggressive liquids in the short and long-term mechanical behaviour of polymers and polymeric matrix composites
44. Polymers and polymeric matrix composites for low velocity impact
45. Methodology of design of gears in polymers and polymeric matrix composites
46. Methodology of design of bearings in polymers and polymeric matrix composites
47. Processing of elastomers
48. Methodology of design with elastomers
49. Strain rate sensitivity of polymers and polymeric matrix composites
50. UV sensitivity of polymers and polymeric matrix composites
51. Joining processes of polymers and polymeric matrix composites
52. Deployable structures with polymers and polymeric matrix composites
53. Simultaneous influence of temperature, humidity and aggressive environment in short and long-term behaviour of polymers and polymeric matrix composites
54. Short and long-term biocompatibility of polymers and polymeric matrix composites: characterization, methodology
55. Smart polymers and polymer matrix composites: types, characterization, processing
56. Polymers and polymer matrix composites for high speed impact
57. Wear behaviour of polymers and polymeric matrix composites
58. Machining of polymers and polymeric matrix composites
59. Polymers and polymeric matrix composites with low friction coefficient: applications, characterization, processing
60. Blow moulding: process simulation
61. Processing of polymeric matrix composites
62. Polymers and polymeric matrix composites with functional gradient
63. Polymer alloys
64. Hybridization polymeric matrix composites
65. Characterization of polymers and polymer matrix composites for tires “not” tyres (NPT-non-pneumatic tyres)
66. Multi material injection moulding
67. Manufacturing tolerances of polymers and polymeric matrix composites
68. Gas-assisted Injection Moulding: process simulation
69. Welding processes of polymers and polymeric matrix composites
70. Design of mechanical polymer connections and polymeric matrix composites
71. Design of a “skate” in polymers and polymeric matrix composites
72. Design of a shelf in polymers and polymeric matrix composites
73. Design of a Coca-Cola bottle
74. Design of a plastic bag
75. Fire behaviour of polymers and polymeric matrix composites
76. Polymeric foams: applications, characterization, processing
77. Design of hyperplastic polymers and polymeric matrix composites
78. Cleaning tools used with polymers and polymeric matrix composites
79. Electromagnetic properties of polymers and polymeric matrix composites

Results Analysis

Regarding the reports submitted by the students from 2008 till 2017, the deficiencies and difficulties experienced allow us to draw the same conclusions already presented regarding the reports on ceramic materials—analysis and discussion of a scientific article.

Classroom presentations of the theoretical work have been carried out without difficulty and most of the students present a very good level of quality. These presentations are also a preparatory work for the master's thesis defenses and presentations that are often necessary in a work context.

The monograph proved to be a very useful tool for both students and teachers. The formers allowed the consolidation of the concepts discussed and led to the creation of new links between them, since the same issue is approached from different perspectives. For professors allowed the formative evaluation and the detection of difficulties in understanding concepts and the opportunity to again explain them, individually or in large groups. The writing of the monograph is seen as a relevant and effective preparatory work for more in-depth monographs, such as the master's dissertations to be presented and defended at the last semester of the MIEM.

The main problem identified during the last years was the late start of the writing of the monograph which is reflected in some lack of organization and verification of the contents. The main reason may be the inertia to begin the writing exercise, that only disappears gradually with continued practice and, still the difficulty that some students feel in organizing and summarizing high amounts of information.

3.2 Metallic Materials

Learning outcomes and competences

It is expected that in the end of CU students will be capable of understanding and anticipate steel and cast irons microstructures based upon chemical composition and heat treatments. Also they must be able to relate microstructures with mechanical properties such as strength, ductility and toughness. It is expected that students know and understand main delivery states of metallic alloys and the meaning of their heat treatments. Finally, they must be able to do materials selection based upon their mechanical and technological properties. Also they must be able to choose or specify heat treatments based on predefined objectives [26].

The CU of Metallic Materials (MM) of MIEM, second year, second semester, has 6 ECTS and a total of 56 h of contact (28 h theoretical and 28 h practical, both of 2 h classes per week). The course demands a total 162 h work, divided among classes, exams, study, development of the practical work outside the classes, and a technical visit to a company that is a steel heat treater and a commercial consultancy and steel distributor (Ramada, Ovar, Portugal) which cooperates with the CU, supplying leftovers of steels for the metallographic samples and steels to make the samples for the mechanical tests.

Experimental work:

The practical classes are taught in a materialographic laboratory by different professors with the support of a technician, for maximum of 22 students in each class (around 160 students in total). The first 4 classes are intended to present the subject covered on the experimental work. The idea of the classes is to supply the necessary tools for students' startup with the work. During these classes some handouts are given to students as well as some exercises and assignments to solve during the classes.

The remaining practical classes are entirely dedicated to the experimental work, done in groups of two students (exceptionally 3). Although they may choose topics outside the steels world, the normal procedure is working with this group of materials because the heat treatments are more complex and just to use the metallographic consumables for steels during samples preparation for metallographic analysis (no contamination if someone is using a softer material).

The typical eight topics covered are:

1. Quenching and tempering
2. Austempering
3. Normalizing
4. Spherodization
5. Temperability determination—Jominy test
6. Carburizing
7. Charpy test in normalizing and tempered condition
8. Identification of real components made of ferrous alloys

Students receive one handout with all the instructions to elaborate the final report and the A4 poster, the due date and the final presentation and discussion dates. The document also includes a set of instructions of how to write a technical report. These instructions cover the following items:

- Title of the work;
- Contents;
- Abstract and objectives;
- Introduction;
- Literature review;
- Study of the supplied material (prediction of the hardness and microstructures and experimental analysis of these two parameters and discussion);
- Study of the heat treatment (definition of the heat treatment cycle, forecast of the hardness and microstructure, experimental determination of these two parameters and discussion);
- Conclusions;
- Future work;
- References;
- Annexes.

The other supplied document is specific for each group, according to the type of the experimental work selected from the 8 topics above referred. This document focuses on the following items:

Objectives and general methodologies:

- Identification of the steel group;
- Characterization of the group through typical properties, applications, manufacturing processes and other important elements;
- Individualization of the material inside it's group. Comparison with other steels of the same group;
- Study of the possible microstructure in the as supplied state. Relation with the forecast metallographic state:
- Draw a schematic of the forecasted microstructure;
- Confirmation of the schematic through the samples already prepared;
- Program the experimental work to be developed. Define the heat treatments and anticipate the final microstructures and hardness;
- According to the heat treatment cycles defined, do the adequate treatment to all the samples;
- Confirm the results obtained by comparing them with the predicted ones;
- Design and perform adequate complementary tests to clarify some doubts relatively to the results obtained.

The type of experimental work, as specified before, can cover different heat treatment cycles, but in generality, each group receives 3 samples (exception for Jominy and Charpy tests). One of the samples is kept in the "as supplied state", and the other two are intended to study the effect of one heat treatment parameter, for example temperature, dwell time at the heat treatment temperature, cooling medium, protective atmosphere, or other interesting factor.

The first seven types of work have clear rules and indications, and students are more or less conducted to the final result. On the other hand, the work number 8 (Identification of real components made of ferrous alloys) is freer, considering that students have to bring to the classes one component that they are curious about the material that was used in its construction [27]. This type of work is more demanding, and is usually chosen by the students that have a more practical intuition or are more adventurers to accept this challenge. Many times they can choose components that are available at classes and that are the result of visits to companies or projects with the industry. The goal of this work is using all the acquired knowledge, professors experience and all the available experimental facilities in DEMec FEUP, to define and execute several heat treatments that can give inputs to help in understanding and identifying the possible type of steel (metallic material) used in that specific application.

Considering this, one presents some of the details of this last type of work.

The following are some of the material identification works that were done in recent years:

1. Steels used in ancient Portuguese bridges (D. Luis, Pinhão, Trezoi and Viana), see Fig. 6. When these bridges were repaired, the degree of steel degradation was evaluated in FEUP and some leftovers were kept in the materialographic laboratory. Figure 7 shows some fractured tensile specimens machined from the Trezoi Bridge.
2. Steels for files (Fig. 8 left)
3. Circular saws (Fig. 8 right)
4. Racing car transmission shafts (Fig. 9)
5. Gears and brakes (Fig. 10);
6. Knives and blades (Fig. 11)
7. Springs
8. Tools and others.

The work starts with the characterization of the supplied part (measurements, pictures, and search data on books and www) on the "as supplied condition". Cut of samples for analysis. When they are supplied in the "as treated" condition, samples

Fig. 6 D. Luis (Porto) and Pinhão (Pinhão) bridges

Fig. 7 Tensile specimens machined from the Trezoi Bridge

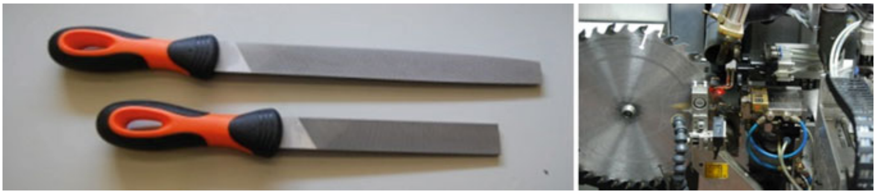


Fig. 8 Files and circular saws

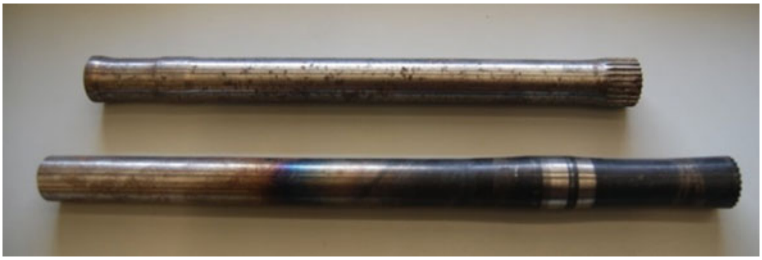
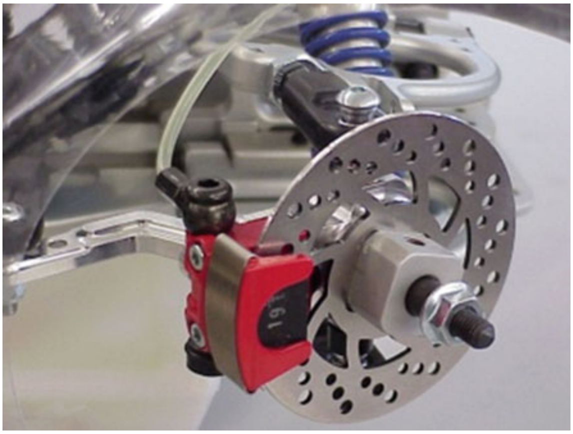


Fig. 9 Racing car transmission shafts axles

Fig. 10 Break system



are cut with an abrasive disc with abundant refrigeration to avoid heating the part and change the hardness.

After this phase, and in case of having small pieces, the samples are cold or hot (preferably, because it is fast) mounted in a thermosetting resin support to allow an easy hand polishing. The polishing sequence adopted is water grinding with SiC paper abrasives (grits #80, 180, 320 and 800), followed by polishing with clothes impregnated with alumina and diamond (3 and 1 μm), respectively.

Fig. 11 Kitchen knives in martensitic stainless steels

The metallographic attack is usually done with Nital 2% (2% nitric acid and 98% alcohol). When necessary, a specific reagent is prepared according to the recommendations of Metals Handbook [28] or other books. Samples are then analysed in an optical microscope (Zeiss, Germany) and digital micrographs are obtained. In some cases, if needed, electronic microscopy (usually SEM and microprobe analysis) can be performed at the Centre of Materials of University of Porto [22].

The hardness is determined using Brinell, Rockwell C or Vickers (also micro hardness) scales.

After this point, and using books, as good examples one can cite references [29–35], catalogues (Ramada [36], Thyssen, SSAB and others), CES Edupack Software [23], in house performed dilatometry tests and diagrams of isothermal and continuous cooling transformations, available at the laboratory or other internet data, students' define the heat treatments to perform in the heat treatment laboratory furnaces. The heat treated samples are then polished and etched for microstructural analysis and hardness determination. Figure 12 shows some of the stages during the experimental work.

In the presence of all the results obtained, students compare the experimental results with the theoretical ones, and if any doubt still exists, they can repeat some of the heat treatments to confirm some of the data.

After this stage they start to elaborate the report in the classes, under professors' supervision, and prepare themselves for the final presentation and discussion.

The reports are corrected by the professors that during the final presentation (7 min for each group, followed by an 8 min period of discussion) ask questions about the report but also about the entire subjects taught in the classes. During the discussion other students are also encouraged to participate and are asked questions by their colleagues or teachers.

After the end of classes a simple inquiry, using the Google Drive tool was produced. Students were free two answer, and 25% of them collaborated in this work, with 90% thinking that the experimental works are very important to learn the topics covered on theoretical classes, with 10% saying that is few important. None said that is no important.

Fig. 12 Visit to a steel company, experimental classes and heat treatments laboratory

Students considered the experimental works very challenging, although some of them said that they finished the classes with a deep knowledge about their specific steel but without much knowledge about other steels. We cannot agree with this comment because in the end of semester, students have public presentations of the work and can raise questions and participate actively in this process. In our point of view they are not paying attention to other presentations because they are just worried with their own work.

Students considered that the time available to do the experimental work is adequate and that the identification of components is challenging, but very demanding, needing an even more intense collaboration of professors and laboratory technicians.

4 Conclusions

The use of the presented methodologies contributes significantly to the students of the MIEM to acquire the CDIO and EUR-ACE competences indicated for mechanical engineers.

The introduction of the Project-Based learning assessment in the Non-Metallic Materials Curricular Unit of the Integrated Master's Degree in Mechanical Engineering of the Faculty of Engineering of the University of Porto has successfully changed the way students study and learn the contents related to ceramic, polymeric materials and polymer matrix composites.

It has been shown that evaluation based on a practical work of a scientific paper about ceramic materials or on a current topic about polymer or composite materials that requires considerable research on the World Wide Web and databases of scientific articles, followed by the elaboration of a report, an oral presentation and a public debate is a very demanding job that the students appreciate and actively participate. This structure facilitates their learning and enrollment in the curricular unit, increasing their knowledge about the materials studied and contributes to the development and improvement of their research and synthesis capacities, in writing reports and doing presentations that they will constantly need in the near future.

The introduction of a strong experimental component on the materials classes about metallic materials promotes a great students enrolment on the classes with excellent final practical grades that are responsible for the elevated percentage of final approvals in the MM classes of MIEM's Master program.

Students appreciate the type of experimental work proposed, because they have to do, themselves, samples preparation, microstructural analyses, mechanical tests and heat treatments, interpret, present and discuss the results obtained. They can propose experimental works with materials related to mechanical construction and with the ones that they, from any reason, were involved in their use.

This type of work, although very demanding, is recognized by the students that it is extremely motivating, offering them an excellent opportunity to learn by doing. These classes have been evolving for more than 30 years and when present engineers are asked about the memories of the course, they all seem to remember their materials classes' work they have done. Nothing is more rewarding for a teacher than the perennity of is teachings and influence.

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