

# The Teaching of Metrology

The genesis and the epilogue of a degree

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## ABSTRACT

Metrology, as a measurement science and its applications, has a widely recognized importance in all areas of human activity where accurate measurements are required to ensure user confidence and universality. The emergence of new technologies, new methods, new products and new areas of development have definitively placed metrology as a fundamental science in all areas of human activity. Associated with the reasons already mentioned, one cannot fail to mention the economic question of globalization that was only possible due to all the activities related to metrology. As a scientific area, metrology strengthens the development of measurement capabilities, and plays a key role in innovation, quality assurance of products and decision-making. This work approaches the teaching of metrology in Portugal in the first institution of higher education of the country to offer in its training a bachelor's and a master's degree in Instrumentation and Metrology Engineering. So, this work analyses the past, the present and the future of this branch of engineering from the perspective of the first institution of higher education teaching it in Portugal. The solution to solve the gaps found was to diversify the offer of metrology training, but also to spread the importance of this science to students in other study cycles.

## KEYWORDS

Metrology, Teaching, Engineering, Measurement, Bachelor, Master, Level 5 training.

## 1 Introduction

Metrology, a field of knowledge related to measurement, has a transversal nature to all engineering specialties and serves a wide range of economic (or applied), scientific and legal activities (Figure 1):

- Scientific metrology: covers the achievement, the development and the maintenance of national standards of measurement units (but scientific metrology is not only concerned with the definition of magnitude and corresponding units, it is also concerned with its physical materialization);
- Applied metrology: establishes the traceability of the reference and work standards to be used by the scientific

and the industrial community, the evaluation of the uncertainty of the measurements made in the scope of the measurements of the production and transformation of goods for the demonstration of the metrological quality;

- Legal metrology: approve and verify the measuring instruments used in commercial, industrial, hospital, tax and other regulated applications.

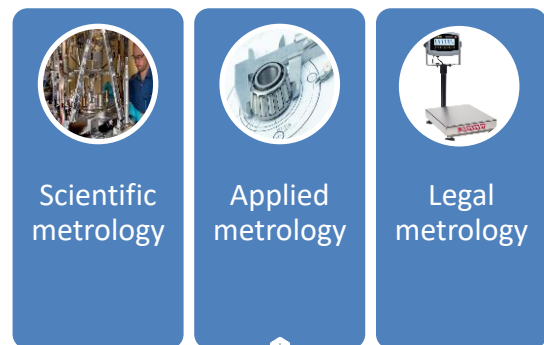


Figure 1: The three areas of operation of metrology.

In Portugal, metrology is framed by Decree-Law No. 71/2012, of March 21, as an integral part of the Portuguese Quality System, which is supervised by the Ministry of Economy. The Portuguese Quality System (SPQ) is constituted by three subsystems (Figure 2):

- Standardization;
- Qualification;
- Metrology.

The metrology subsystem has assumed relevance and development in the last decades, due both to the requirements of the ISO 9000 (regulates the fundamentals and vocabulary of the quality management system) and ISO 14000 (establish guidelines on the area of environmental management) standards families and to the accreditation of calibration and testing laboratories, as well as to the application of Community Directives transposed into Portuguese law.

With metrology in all human activities, the European Association of National Metrology Institutes (EURAMET) estimates that, in developed countries, the activities and associated activities represent 6% of its Gross National Product (GNP), which in the case of Portugal reaches a value of approximately 10 billion Euros.



**Figure 2: The three pillars supporting the Portuguese Quality System.**

Then, it becomes obvious that good metrology skills are important, but, being such an important economic and social activity, the question that arises is: Who forms technical specialists in this area?

This work intends to address the creation, the implementation and the operation of a bachelor's, is a three-years degree, following the Bologna Treaty (180 ECTS), and a master's degree in metrology in Portugal. These are taught by the Institute of Engineering of Porto (or ISEP from Portuguese designation Instituto Superior de Engenharia do Porto), a unique case in the offer training in the country. With this experience we intend to contribute to the diversification of training in higher education in this area of measurement science presenting some of the possible solutions and training offers.

## 2 The experience of Metrology teaching in ISEP

### 2.1 Background

The Instituto Superior de Engenharia do Porto is an organic unit integrated in the Polytechnic Institute of Porto (P.Porto) with a vast experience in engineering education accumulated throughout its 167 years of existence. At present, ISEP has about 7000 students enrolled and distributed by a training offer of (in Portugal, the schools of polytechnic institutes, unlike universities, cannot teach or confer doctoral degrees):

- 12 bachelor's degrees;
- 12 master's degrees;

- 22 postgraduate courses;
- Several modular formations of short or long duration.

The functional structure of ISEP is divided into nine independent departments, one of which is Physics Department (DFI), where the bachelor's and the master's degrees in Instrumentation and Metrology Engineering were created and be managed, but it should be noted that many of the activities take place in other departments of the institution (for example, Chemical Engineering Department).

ISEP's proximity to the surrounding business fabric, which goes through the research and development of projects, service provision and consulting, allows it to be attentive to the training needs of the companies and, as a result, the creation in 1991 of the bachelor's degree in Engineering of Instrumentation and Industrial Quality (or LEIQI from Portuguese designation Licenciatura em Engenharia de Instrumentação e Qualidade Industrial) to meet the growing demand for specialized human resources in the area of industrial quality derived from the need for companies to obtain certifications. During its fifteen years of operation, it has trained hundreds of senior executives who are now prominent in industry and accredited testing and calibration laboratories.

Taking advantage of the need to adapt existing courses, as a consequence of the signing of the Bologna Treaty (has jointly established a European Higher Education Area based on the commitment of the signatory countries to promote reforms of their education systems), and having identified the lack of higher training in metrology area, LEIQI was adapted to the requirements of Bologna and in 2006 resulted in the creation of the bachelor's degree in Instrumentation and Metrology Engineering (or LEIM from Portuguese designation Licenciatura em Engenharia de Instrumentação e Metrologia). The main goals of the LEIM are training professionals with expertise in the metrology field, which have the adequate skills to fulfill positions at accredited metrology laboratories, institutions of the branch, municipalities (essentially with legal metrology) and all kind of companies (for example, from the automotive sector). But, in the professional world, this area is easily found in almost every sector of activity, because, the related skills are the basis of innovation and technological development of all companies in any sector of economic activity (from agriculture to services).

This change was not simply confined to the degree name modification. The curricular structure of the course was elaborated by reinforcing the part related to metrology with curricular units (UC's) that cover the various branches of physics (Mechanics, Optics, Thermodynamics, Fluids and Heat Transfer, Electromagnetism, Acoustics, Materials, etc.) where the theoretical concepts needed to understand the phenomena were complemented with a very strong practical and laboratory component. In parallel, given the solid link between these two areas, the instrumentation part was also reinforced (Data Acquisition and Management, Applied Instrumentation,

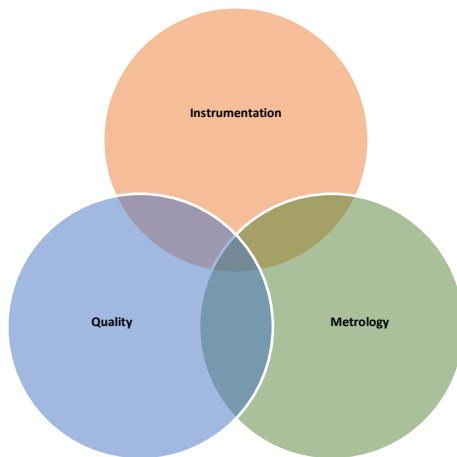
Instrumentation and Control Systems, Signal and Image Processing, etc.).

The LEIM can then be characterized as a multidisciplinary training since it covers the different scientific areas related to engineering where metrology is present.

## 2.2 LEIM curriculum structure

The course study plan, with six semesters of teaching activities, was constructed based on three complementary areas, which are interconnected (Figure 3) and which are essential to the domain of a measurement system.

- Metrology (a scientific area of physical engineering);
- Instrumentation (a scientific area of electrotechnical engineering);
- Quality (a scientific area of mechanical engineering).



**Figure 3: Interconnection of the key areas of LEIM.**

The curricular structure of the cycle of studies was conceived in order to exist a coordination between the UC's and their programmatic contents, in order to guarantee coherence with the defined objectives.

Teaching methodologies of LEIM have been adapted to know and to do. Table 1 presents the bachelor's degree in Instrumentation and Metrology Engineering study plan, which was established taking into consideration the development of these fundamental aspect.

**Table 1: LEIM study plan.**

1 <sup>st</sup> Year   1 <sup>st</sup> Semester	1 <sup>st</sup> Year   2 <sup>nd</sup> Semester
Linear Algebra and Analytic Geometry	Technical Drawing
Algorithm and Programming	Electromagnetism
Experimental Physics	Applied Instrumentation I
Introduction to Metrology	Mathematics

Mathematics I	Programming
<b>2<sup>nd</sup> Year   1<sup>st</sup> Semester</b>	<b>2<sup>nd</sup> Year   2<sup>nd</sup> Semester</b>
Statistics	Numerical Analysis
Applied Instrumentation II	Data Acquisition and Management
Mechanical Metrology	Materials Science
Chemistry	Fluids and Heat Transfer
Applied Thermodynamics	Optical Metrology
<b>3<sup>rd</sup> Year   1<sup>st</sup> Semester</b>	<b>3<sup>rd</sup> Year   2<sup>nd</sup> Semester</b>
Management	QAS Management
Analytical Instrumentation	Image Processing
Acoustic Metrology and Vibrations	Project / Internship course
Signal Processing	Optional (minimum of one from): Automation and Control; Organizational Behavior; Statistical Quality Control; Project Management; Marketing and Business Management; Optoelectronics and Optical Fibers; Electromechanical Systems; Quality Techniques; Systems Theory
Distributed Instrumentation and Control Systems	

One of the gains in this degree was the insertion of the Project / Internship course (with 15 ECTS), which is compulsory in the last semester of the course, in companies of the branch for a minimum and exclusive period of three months.

In addition to be an integrated curricular unit of acquired knowledge, it also allows the transition between the academic environment and the labor market, facilitating the access of the graduated students to the first job. Often, upon completion of the degree, it is in the company where they completed the internship that the new graduates obtain their first job. The requests of trainees by the companies always surpassed the available number of students.

It should be noted that the employability rate in this bachelor's degree was 100% (according to data and statistics on employability of higher education courses provided online by the Portuguese Ministry of Science, Technology and Higher Education).

Associated with this training offer, the master's degree in Instrumentation and Metrology Engineering was created in parallel. In this second cycle of studies, with a duration of four semesters, for example, concepts of metrology in nanotechnology, calculation of uncertainties using the Monte Carlo method, etc. are given. In this degree, the curricular unit of Dissertation / Project / Internship course income place in the last academic year but during the third semester it takes place together with other subjects. It should be noted that this study cycle was sought by both undergraduate students who wanted knowledge acquired earlier, either by the staff of companies seeking to increase their professional skills in this area.

### 2.3 The search for the LEIM study cycle

The bachelor's degree in Instrumentation and Metrology Engineering, being a young undergraduate degree, distinguished from the classic engineering and a unique training offer in Portugal, was seen by the candidates to the higher education with a certain mistrust. On the one hand, because metrology is not a very visible or widely disseminated science and, on the other, because it is confused with the prediction of atmospheric conditions.

In the first five years of operation, the number of candidates was quite significant, although this did not translate into an effective willingness to attend this degree since their choice as a first option in national contest for access to higher education was reduced. However, after admission and attendance of the course, his dropout was almost residual.

An intensive dissemination work was carried out through the organization of study visits, lectures, symposia, news in the media, short courses and actions taken in secondary and professional schools. However, despite these actions, the number of candidates has declined sharply in recent years. As an example, the number of candidates for this bachelor's degree in the academic year of 2013/14 was thirteen students and in the following academic year, only seven.

This reduced number, two consecutive years with an average value of candidates less than ten, dictated that in 2016 no vacancies of access to this degree were granted, which consequently led to its closure (as determined by the Ministry responsible for higher education). In 2019 they defended their final course work (this is, the Project / Internship course carried out in a business context) the last students still enrolled in the bachelor's degree.

As an effect of this decrease in the number of graduates in Instrumentation and Metrology Engineering, the number of candidates for the master's degree also decreased significantly, and no edition has yet been opened.

From 2006 until its closure, at the end of this current school year, P.Porto graduated ninety-six students with the bachelor's degree in Instrumentation and Metrology Engineering, that is a clearly insufficient number considering the companies lack of human resources in this specific area.

It is unequivocal the need of professionals in the area of metrology, as evidenced by the constant requests of graduates even after the announced closure of the bachelor's degree in Instrumentation and Metrology Engineering.

However, the question now is: is it worth channeling increasingly scarce funds to maintain a bachelor's degree whose demand from student's applicants to higher education is insufficient for several years?

And if the answer is negative, which way(s) to follow?

### 3 Faced with a problem, finding solutions

From the foregoing, it can be possible to see that bachelor's degree in Instrumentation and Metrology Engineering did not have enough adhesion, making its continuity very onerous and, therefore, its inevitable closure.

This setback led to an intense and thorough reflection on the factors that led to non-adherence of candidates to a degree in this area of training, with a 100% graduate's employability rate. The challenge was, through the identification of the factors justifying the closure of this training offer, to find solutions in order to give continuity to almost three decades of acquired knowledge, use of laboratory equipment in this area, follow-up of established partnerships and, fundamentally, existing needs in the market of technicians with knowledge in this structural and very specific area.

This challenge worried for a long time many of the stakeholders in metrology activities in Portugal. Some measures are in the implementation phase and are summarily described in the following points.

#### 3.1 CTeSP in Metrology, Instrumentation and Quality

Precisely in the year in which there were no vacancies for access to the bachelor's degree in Instrumentation and Metrology Engineering, the Professional Technical Higher Courses (or CTeSP from Portuguese designation Curso Técnico Superior Profissional) were took effect in Portugal with the entry of Decree-Law no. 43/2014, of March 18, in the wording given by Decree-Law no. 63/2016, of September 13, which provided that these courses corresponded to a new type of non-academic higher education, only taught in polytechnic higher education system, aiming to introduce, in the scope of higher education, an educational offer of a professional nature situated at level 5 of the European Qualifications Framework for Lifelong Learning, approved by the recommendation of the European Parliament and of the Council of 23 April 2008.

These courses were designed to allow students to:

“The acquisition of a qualification level 5 qualification of the National Qualifications Framework (or QNQ) and aim to constitute as the basis for the development of an area of professional activity, for personal development and for the pursuit of studies, with a view completion of a bachelor's degree course.”

The course, with only four semesters and the last dedicated exclusively to the Practical Training in Work Context, has a study plan was constructed based in the three complementary areas (as previously described, metrology, instrumentation and quality) that were the basis of the previous bachelor's and master's degrees. In addition, there are also the UC's related to the scientific competences (mathematics and physics) and computer science of any engineering course.

With this new training offer, the opportunity arises to maintain metrology's instruction in a Portuguese higher education institution, allowing students to graduate in this professional formation, with solid bases in the areas of metrology, instrumentation and quality, to continue studies for obtaining a bachelor's degree in one of the two areas that serve as the basis for this specific scientific area:

- Electrotechnical engineering;
- Mechanical engineering.

This duality of a technical training in metrology associated with the possible access to more traditional degrees in engineering is an added value for small companies that sometimes have difficulty to hire technicians of diverse specialties, obtaining with a single professional a complementarity of technical and scientific formation.

### 3.2 Post-graduation in Metrology and Quality

To fill the gap left by the master's degree in Instrumentation and Metrology Engineering, was created in 2018 a post-graduation in Metrology and Quality.

This was the first initiative of its kind in Portugal and was developed in partnership with the Portuguese Electrotechnical Institute (or IEP from Portuguese designation Instituto Electrotécnico Português), an accredited laboratory for various types of metrology tests. It should be noted that this training also had the collaboration and support of the Portuguese Quality Institute (or IPQ from Portuguese designation Instituto Português da Qualidade), which owns the national primary laboratory and supervises all activities related to metrology in Portugal. Other institutions of the metrology area were also associated, directly or not, to the course.

The first edition of this training ended recently (April 2019) and had, according to the surveys carried out with the graduates, the student's employers and the teachers, an enormous professional and academic acceptance and relevance. These questionnaires also allowed to understand some of the recent needs of companies in the area of metrology, so the course curriculum will be quickly changed to fill these needs.

## 4 Final considerations

It is agreed that metrology works as an indicator of the capacity for innovation, which has assumed a growing relevance with technical and technological development, and which is the guarantor of the quality of products and services.

It is the fundamental basis for the economic and social development of a country, for the competitiveness of enterprises and for consumer protection. Consequently, the need for technicians with solid training and full control of the science of measurements is unequivocal.

From the experience presented, it was verified that the training offered by a bachelor's degree in metrology, and consequently of a master's degree in the same area, did not have enough adherence on the part of the students, making its continuity economically unsustainable.

The solution was then to diversify the offer of training in the metrology area through other types of higher education courses, but also for the dissemination of the importance of metrology to students in other study cycles.

Most of the population and secondary school students are unaware of metrology activities. It is essential that the basic education system provide metrology teaching (in the form of a module, for example) in its curricula, in order to instill knowledge and raise awareness of its importance in the various activities. Only in this way can one achieve the goal of naturally attracting students to this area of vital importance for the development of society and of course, a country.

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