

2023

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Recommended Citation

Aleixo, S. M., & Martins, S. G. (2023). LMATE: An Innovative Bachelor Degree Connecting Mathematics And Industry. European Society for Engineering Education (SEFI). DOI: 10.21427/Q9KQ-YM60

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LMATE: AN INNOVATIVE BACHELOR DEGREE CONNECTING MATHEMATICS AND INDUSTRY

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Conference Key Areas: *Engagement with Industry and Innovation, Curriculum Development*

Keywords: *Applied Mathematics, Innovative Bachelor Degree, Partnership with Industry, Enterprise Internship, Transdisciplinarity*

ABSTRACT

The bachelor degree in Mathematics Applied to Technology and Enterprise (LMATE) has an innovative structure, working in partnership with industry, involving a transdisciplinarity curriculum plan, with a solid mathematical base including extensive knowledge in statistics, optimization, modeling and programming (Python, R, etc.), along with training in engineering, physics and management.

LMATE presents three differences in relation to other applied mathematics portuguese bachelors degrees: it was constructed upside down towards the usual,

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once partner entities (enterprises, public entities and research centers) were consulted on relevant mathematical contents to solve their problems, instead of being created exclusively by the academy; in its curricular plan has optional curricular units from several engineering areas; and is the only bachelor degree in applied mathematics that has an internship integrated.

As LMATE performance evaluation measures the following can be listed: the number of partner entities has increased to 37 currently; demand has been far greater than the offer of vacancies, reaching around 800%; average entry grades have been increasing (from 12.6 to 15.2); and more than 70 of the 176 students who entered in the six years of LMATE have graduated, having done internships in partner entities.

Based on a follow-up study of students who have already finished LMATE to assess the quality of the knowledge acquired and its employability, it is concluded that many of finalists enroll in master's degrees, the majority just after LMATE; others enter the labor market straight away, but all feel that LMATE provided them with adequate preparation.

1 INTRODUCTION

Many of the developments in our society are undoubtedly driven by science and technology, making it imperative to apply different mathematical concepts and methods, most of them driving to optimal results which increase sustainability. In 2021, the UNESCO Director-General said that mathematics support all areas and plays a key role in artificial intelligence and technological disruptions along with algorithms; when global issues such as the COVID-19 pandemic, climate change and sustainability are addressed, the importance of mathematics in responding to current challenges is perceived (UNESCO 2023).

The universe of Mathematics applications is vast, there are several areas of human knowledge, namely all natural sciences and engineering, medicine, economics or social sciences. There are also numerous branches of mathematics to which these areas apply, among which modeling, optimization, statistics or computer science, can be highlighted (Pepin, Biehler and Gueudet 2021, 166). Despite this intrinsically interdisciplinary context, the vast majority of existing classical applied mathematics bachelor degrees have, for students, an apparently limited action in applications.

Interaction with external stakeholders is highly recommended to develop students' skills and abilities. In addition, it is important to adapt students' learning to the needs of stakeholders, allowing optimizing processes and resources, as well as increasing competitiveness, and fostering the sustainability of companies/industry (Hoinle, Roose and Shekhar 2021; Gorgul and Erden 2022, 1206; Herzog et al. 2022). Faced with this reality, one of the authors, as president of Mathematics Department (MD), triggered the construction process of a new Bachelor Degree: LMATE.

2 CONTEXTUALIZATION

LMATE intends, without giving up a rigorous mathematical training, to enable its students to solve issues raised by society, by institutions and companies from

several areas or from other sciences and technologies, in close connection with institutions generators of development, competitiveness and more sustainable solutions. In order to base the construction of this bachelor degree proposal, the MD of the Higher Institute of Engineering of Lisbon (ISEL) carried out a careful study about the existing applied mathematics degrees, not only in Portugal but also abroad. This study proved to be particularly enlightening in identifying training combinations not yet explored by national higher education institutions, in which it was still difficult to recognize any connection to institutions and business organizations. Some inspiring degrees were: Industrial Mathematics at Bremen University in Germany, and Mathematics with specialisation in Statistics, Econometrics or Mathematical Engineering at Autonomous University of Barcelona in Spain. LMATE was inspired by these degrees with a strong mathematical and computer base, different curricular units (CU) linked to industrial mathematics, modeling and management. However, although these courses have a final degree work with significant weight, they have no connection to companies during the degree like LMATE. Aware of the pertinence and the need to strengthen the relationship between the academy and the community (Feron, Poinsothe and Jossic 2022) the MD established multiple contacts and promoted several work meetings with heads of different companies and entities, many of which have an undeniable economic and social role. These contacts, all of which were well received by enterprises and institutions, resulted not only in a crucial contribution to the structuring of the bachelor degree, integrating fundamental contents into the syllabus of the CU, but also in triggering their participation in seminars and workshops integrated into the degree, as well as the offer of internships, resulted in a unique training offer and an even greater alliance between ISEL and the scientific and technological community. LMATE presents three fundamental differences in relation to other applied mathematics degrees existing in Portugal: 1) It was constructed in the opposite way to the usual, in the sense that the subjects that the partner institutions considered to be relevant to later apply in solving their problems were identified first and after were inserted these themes in the syllabus of the CU. That influenced also which CU that should be part of the curriculum. Instead of the degree being designed solely by the academy; 2) It has in its curricular plan optional CU from the various areas of engineering at ISEL, in order to familiarize students with important areas that they will integrate when they go to do internships at partner entities; 3) It is the only undergraduate degree in applied mathematics that has an internship integrated into its 3-year curriculum structure.

The structure of the proposed degree thus resulted in innovative, forceful and flexible training in the Portuguese reality, both in terms of differentiation in relation to the existing offers in higher education, and in the needs of companies and entities in the country.

3 LMATE

3.1 Bachelor Degree objectives

LMATE intends to develop and apply, in a multidisciplinary context, advanced mathematical and computational methods in the formulation, resolution and interpretation of relevant problems in different domains, in particular real problems raised by the several branches and sectors of activity (many of them improving sustainability). In this sense, LMATE is aimed by candidates with varied profiles and interests, aspiring to provide its students with a considerable set of scientific and professional skills.

The set of CU that make up LMATE, aims to offer its students solid knowledge that will allow them an early and successful entry into the job market, or, if they prefer, the continuation of their studies in masters in a diverse set of areas.

The LMATE curricular flexibility seeks to be made up of current, appealing and multi-disciplinary options, in areas such as mathematics, engineering, physics and management, where the greatest possible advantage is taken of the training offers of other ISEL departments. Throughout the training course, MD has promoted seminars/workshops, carried out by professionals from partner entities, so that LMATE students become familiar with research projects since the first curricular year. The biggest challenges presented by the partner entities are for the internship themes, and the smaller ones will be, whenever possible, object of study in the curricular units designed for this purpose.

The bachelor degree culminates in an internship at a partner entity or in a project that provides:

- obtaining knowledge and experiences advocated by the articulation between theory and practice;
- autonomy in the acquisition of scientific knowledge necessary to carry out the proposed tasks;
- the development of relevant and necessary skills, habits and attitudes for the acquisition of professional skills;
- a closer relationship between ISEL and the community.

By contemplating the elaboration of protocols with partner entities, LMATE favors the integration of graduates in the labor market.

3.2 Students admission

Initially, were assigned 30 vacancies to LMATE for the national competition for access to higher education (CNAES). In 2018, due to national politics it became 28 vacancies.

Since its first year of operation, LMATE has had all of its vacancies filled in the first phase of the CNAES. The few registrations not carried out in this phase, automatically transferred to the second phase, were also completely filled out. Between 30% and 40% of the placed candidates choose LMATE as their first option. Some statistics about students who entered LMATE can be consulted in Table 1:

Table 1. Statistics of candidates who joined LMATE through CNAES

Year	Min.Ph.1	Max.Ph.1	Aver.Ph.1	Plac.Ph.1	Min.Ph.2	Max.Ph.2	Aver.Ph.2	Plac.Ph.2
16/17	11.84	14.00	12.66	30	13.44	13.96	13.70	7
17/18	13.20	15.66	13.80	30	14.68	16.26	14.96	3
18/19	12.80	15.98	13.76	30	13.98	15.50	14.57	6
19/20	13.34	15.66	14.17	28	14.34	15.04	14.69	6
20/21	13.36	16.06	14.24	28	14.74	15.96	15.25	2
21/22	12.72	15.54	13.86	28	14.42	15.42	14.70	6
22/23	14.22	17.20	15.21	29	15.46	16.54	16.04	4

LMATE has recurrently had a demand far greater than the offer of vacancies in any of CNAES phases. Regarding the 1^s phase, Table 2 has some relevant data.

Table 2. Number of 1st phase LMATE candidates, vacancies and demand rate

Lective year	Number of candidates	Number of vacancies	Demand rate
2016/2017	70	30	233%
2017/2018	173	30	577%
2018/2019	240	30	800%
2019/2020	165	28	660%
2020/2021	161	28	772%
2021/2022	109	28	389%
2022/2023	211	29	728%

3.3 Curricular Structure

The curriculum plan proposed for LMATE was distinguished in several aspects of the structures offered in different institutions with training programs in the same area of knowledge in Portugal. The offer of CU in the first year of the study cycle is varied (see Fig.1), covering some fundamental topics for the student to acquire the intended base skills. The diversification of competences is achieved by the progressive offering of a wide range of options, in which the direct contact with the several scientific areas of ISEL is privileged and which will translate into easier adaptation to the interdisciplinarity required by real problems. This way, the student has the possibility of organizing his study plan with predominance in application in one of the engineering areas of his interest. The internship/project (see Fig.2), which may extend to partial regime throughout the 3rd year curriculum (modality 1) or focus on the 2nd semester of the 3rd year (modality 2), will materialize the connection to concrete problems of the business world, consistent with the nature of the study plan. The main areas of LMATE study are: mathematics, statistics, operational research, optimization, numerical analysis, modeling, simulation and programming. LMATE curriculum plan includes 19 mandatory and 7 optional CU. Between the mandatory CU: 4 are in pure mathematics; 1 in numerical analysis that allow them

to learn alternative methodologies to solve insoluble mathematical problems analytically, and other 2 more advanced, mixing analytics and numerical analysis; 1 of Physics, useful in formulate, modelate and solve some kind of specific problems; 4 are in statistics, which enables students to acquire strong training in this necessary area, much requested later in internships and in professional life; 2 in operational investigation and optimization, much useful in solving real labor market problems, allowing to assist decision-making; 1 in Management that allows students to evaluate the economic impact of the new methodologies they apply, and finally, 1 of Modeling where real problems are solved as preparation for the internship. In addition to math options (like Quality and Reliability Control, Bayesian Statistics or Operational Research Complements), students have annually a vast list of other optative CU in physics, engineering and soft skills; namely Machine Learning, Artificial Intelligence, Data Bases, General Chemistry, Electricity Networks and Telecommunications, and Marketing and Interpersonal Communication. The dynamic structure of the LMATE curriculum plane should be emphasized, in the sense that the CU programs changes, given the pedagogical experience that has been gaining with the teaching development, aided by the contribution of partner entities regarding the performance of students in the internships. The contribution of LMATE partners was very important in creating the bachelor degree, but it remains crucial for its update, so that it will increasingly meet the needs of the labor market that becomes extremely demanding.

1st semester	2nd semester
Algebra and Geometry	Vector Analysis
Analysis	Statistic
Discrete Mathematics	Physics
Operational Research	Introduction to Numerical Analysis
Programming	Object Oriented Programming

3rd semester	4th semester
Methods for Ordinary Differential Equations	Methods for Partial Differential Equations
Statistical Models	Multivariate Statistics
Optimization	Modeling
Time Series	Phys. Op. Mat. Op. Eng. Op.
Phys. Op. Mat. Op. Eng. Op.	Phys. Op. Mat. Op. Eng. Op.

Fig. 1. LMATE Curriculum – 1st and 2nd years

5th semester	6th semester
Evaluation and Project Management	
Options in Mathematics Options in Engineering	Internship / Project
Option in Physics	

5th semester	6th semester
Options in Mathematics Physics Options in Engineering	Options in Mathematics Physics Options in Engineering
Internship / Project	

Fig. 2. LMATE Curriculum – 3rd year

3.4 Teaching and Evaluation Methodologies

In general, the several CU work on a theoretical-practical basis, with some working in a computer lab. All subjects have support lessons beyond class hours, and in addition, the teachers are always available to answer questions, existing a great proximity between students and professors. The CU assessment comprises a theoretical part by tests or by exam, but always has a practical component consisting of one or more individual or group assignments. In most cases, practical assignments are submitted to an oral presentation and discussion, which allows validating the learning outcomes and providing public speaking skills for students

future professional life. The strong acceptance of the works carried out by the students in the internship by the partner entities of LMATE, is a strong indicator of the adequacy of the learning results obtained and consolidated throughout the degree.

3.5 Coordinating Committee

Since the beginning of operations, LMATE has had its coordinating committee (CCLMATE) divided into two parts: one academic (as usual) and the other linked to partner entities, responsible by: 1) attracting new entities; 2) determining enterprises mathematical problems for internships and for exercises in classes; 3) booking partner entities workshops/seminars; 4) organizing events involving partners; 5) listening to the opinion of these entities regarding: a) the performance of students in internships, b) students knowledge and c) possible suggestions for the insertion of new syllabus contents in the CU of the degree. This way of operating LMATE has proved to be extremely versatile and profitable.

3.6 Partner Entities

The main added value of LMATE is undoubtedly its partnership with enterprises and institutions, allowing an enriching exchange between academia and the job market, beneficial for both parties. At the creation of LMATE, there were already a dozen partners in several sectors. This number has been growing, so that currently LMATE has thirty-seven protocols signed with partner entities, which essentially cover three types of collaboration: 1) participation in seminars; 2) offer of curricular internships to LMATE students and 3) consultancy projects carried out by ISEL MD professors. These partners cover a wide range of areas, namely, **energy**: EDP, GALP, REN; logistics/transport: Transportes Paulo Duarte, Wurth, A-To-Be (Brisa Inovação), Delta; **metalworking/equipment industry**: Sandometal, Exide; research: CDRSP(IPLeiria), LNEC, IPMA; **pharmaceutical/health industry**: Hovione, Grupo Lusíadas, Alliance Healthcare; **services**: Águas do Tejo Atlântico, Câmara Municipal de Lisboa, Infraestruturas de Portugal, CTT, Tecmic, Secretaria Geral da Economia e Mar, Wikiservice, Carclasse, Antúrio, ISX4 Analytics, Jerónimo Martins; **insurance**: Allianz; **consulting/investment**: Closer, Milestone; Bring Global, Dolat Capital; **telecommunications**: Celfinet, Solvit; mold industry: Iberomoldes, Centimfe; **lighting**: Arquiled; media: Media Capital.

3.7 Internships and Projects

The number of LMATE internships and projects has been growing: 5 in 2018/19, 14 internships and an anual project in 2019/20, 18 internships and 3 projects in 2020/21, 27 internships and 2 projects in 2021/22. In 2022/23, as a result of the pandemic, the number of internships had decrease to 14 and 1 project, accompanying the decrease of students in higher education. As examples, some titles of internship reports are listed, namely: Wind Power Forecast with Machine Learning (REN), Optimization of the allocation of transport services (Tecmic), Use of machine learning techniques in predicting the capacity of LTE cells (Celfinet), Estimate Fishing Effort and Predict Operating Gear (IPMA) and Empirical Statistical

Modeling of Equipment with Monitoring of Lubricants in Service for Proactive Maintenance (Galp).

3.8 Path of students who completed the LMATE degree

Currently, there are about 80 students enrolled, 62% male and 38% female. So far LMATE has 67 graduates. A follow-up study was carried out on the path of students who had already completed the degree, contacting them by phone or by email. Many of the LMATE finalists go on to master's degrees, most of them right after finishing the LMATE. Others enter the labor market straight away. According to the study, it has been concluded that: 1) students who are attending or have already completed a master's degree considered themselves well prepared by LMATE for these masters. Many of the topics to be addressed in these masters have already been covered in LMATE; 2) students consider that the computational tools used in LMATE are an enormous asset in the master's degrees, in addition to helping them to carry out their functions in internships at LMATE's partner entities, as well as in their performance in enterprises where they are currently working; 3) students who are already working consider that the internship was very important for them to enter the job market. Also according to the same study, around 30 former LMATE students are already working in several areas of applied mathematics and computing, namely in consulting, banking, insurance and software companies.

4 FINAL CONSIDERATIONS

LMATE has been successful since its creation in 2016, once it has always filled its vacancies and has a dropout rate around 10%, as others ISEL bachelor degrees. Its students recognize the differences that distinguish this applied mathematics degree from others on the market, due to: 1) its solid teaching in mathematics, but at the same time practical; 2) the use of several software; 3) its dynamic construction aided by partner entities; 4) the support and availability of teachers; 5) internships integrated into the curriculum at well-known enterprises and institutions, which bring them closer together and facilitate their entry into the job market. LMATE finalists have enrolled in master's degrees at ISEL and at other important higher education institutions, and the knowledge acquired at LMATE has proven to be quite adequate for carrying out these masters degrees. Half of the students who finished LMATE (some are still doing their master's) are already in the job market applying their mathematical knowledge. The others are mostly carrying out the master's degree exclusively. The creation of LMATE was an innovation, attracting students who otherwise would not come to an engineering school, allowing a fruitful exchange of knowledge and experiences between these students and engineering students who share some UC and live together at the school. LMATE has conquered its own space in the higher education of Applied Mathematics in Portugal, greatly contributing to this, the performance of its students in internships at partner entities who recognized their work. Since LMATE students, as workers, contribute to the optimal solutions of many processes/resources, they are improving the sustainability of our world.

FUNDING

This work is partially financed by national funds through FCT – Fundação para a Ciência e a Tecnologia under the project UIDB/00006/2020.



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