Master Material sciences

Specialty “Innovative Materials and Energy Systems”

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Graduate Programme E-Mat

Syllabus of the second year for Master’s degree

Nantes Université

Contents

General Overview

INTRODUCTION

E-Mat is a graduate program that takes place in Nantes University. It is an integrated program that opens higher opportunities for those who want to develop their research career path in a doctorate.

This program focuses on the emergence of innovative functional material solutions and optimization of performance, reliability and flexibility for the production, conversion, transfer and storage of energy, energy systems, and advanced devices and technologies. It draws on research excellence in physics, chemistry and engineering of (nano)materials, multi-scale modelling, advanced characterization and thermal management.

It is a part of Master of Material Sciences. **All courses in master 2 are taught in English** and students will have a chance to carry out their research project in an international environment in two of our high-level laboratories (Institute of Materials of Nantes Jean Rouxel, IMN & Laboratory of Thermal Engineering and Energy, LTEN) and to train with specialists on top-level instruments.

CAREERS OPPORTUNITY

Graduating from our program at the Master or PhD level will open great opportunities to be hired in Research and Development department of industrial companies involved in many sectors, such as:

- Materials
- New and Renewable energies
- Energy production, conversion and storage
- Information and Communication Technologies, Microelectronics
- Transportation/Aerospace.

You could become :

- Engineer and executive in Research, Development and Innovation
- Engineer and executive in consulting firms
- Materials engineer
- Academic researcher after a PhD.
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PROGRAM LEADERS ON MASTER 2 LEVEL

Pr. Jean-Luc DUVAIL	jean-luc.duvail@univ-nantes.fr
Pr Philippe POiZOT	philippe.poizot@univ-nantes.fr
Pr Xavier PY	xavier.py@univ-nantes.fr

SKILLS BASED APPROACH

1. Formulate a solution to a complex problem in the field of functional materials, associated processes and energy:
   - ✓ by mobilizing theoretical and technical knowledge and the most relevant models,
   - ✓ by adopting a rigorous scientific approach and reasoning,
   - ✓ by positioning oneself in relation to the state of the art.

2. Develop experimentation/modeling in Materials – Energy :
   - ✓ using validated protocols or those found in the bibliography,
   - ✓ rigorously implement the experimental or modeling protocol,
   - ✓ respecting good laboratory practice,
   - ✓ by developing the experimental/modeling approach to ensure reproducibility and reliability.

3. Analyze data collected in a fundamental or applied research study :
   - ✓ by choosing the most appropriate tools and graphic representations
   - ✓ by critically comparing them with current theories and results found in the bibliographical study,
   - ✓ by exchanging information with specialists if necessary.

4. Integrate Research and Development in a professional industrial or academic environment :
   - ✓ deliver a scientific message that is structured, clear and synthetic, both in writing (article, report) and orally (team meeting, conference), in one's mother tongue and in English, adapted to the audience and context,
   - ✓ respecting the principles of ethics, deontology, environmental responsibility and scientific integrity,
   - ✓ by developing their knowledge and skills through ongoing training and constant monitoring,
   - ✓ by taking part in technological innovation and/or knowledge creation.

TEACHING LOCATIONS

UFR Sciences et Techniques
Campus Lombarderie
2, rue de la Houssinière
BP 92208
44322 Nantes Cedex 3

HOW TO APPLY FOR JOINING MASTER 2 E-MAT

Requirements :

Master 2 level is intended for students with a Master 1 degree in physics or physics-chemistry, or equivalent (240 ECTS).

Language requirement :

- TOIEC minimum 800
- IELTS : 6.0
- TOEFL ibt : 80

Or equivalent Graduate of a university in an English-speaking country

Students applying within the framework of a partnership agreement :

The admission procedure and timetable are detailed on :
https://english.univ-nantes.fr/education/application-procedures/exchange-students

Students applying without any partnership agreement :

The admission procedure and timetable are detailed on :
https://english.univ-nantes.fr/education/application-procedures/regular-admissions

Scholarship

A welcome grant of**1 500€** is available to foreign students enrolling at Nantes Université.
Students can also benefit from a monthly grant of **900€** (subject to eligibility).
Students can also apply to excellence scholarships G. Eiffel or other scholarships proposed by their ambassy.

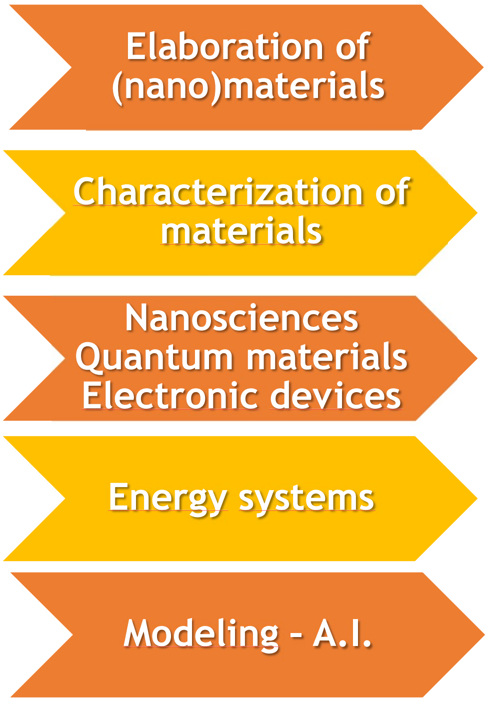
COURSE SCHEDULING

From September to February :	From March to August :
Lectures and practical training	6-month Internship

NB : Students enrolled in a foreign university may do an internship in one of our laboratories at any time of the year, subject to the constraints of their home institution.

PROGRAM STRUCTURE

The teaching program is organized in five teaching units detailed in next sections:



TEACHING UNIT (TU): ELABORATION OF (NANO)MATERIALS 2 (5 ECTS)

Advanced chemical synthesis

Affiliated TU : Elaboration of (nano)materials 2	
Duration : 24h	Number of ECTS : 2
Year/semester : M2/S3	Language : English
Main teacher	Philippe POIZOT
Learning objectives	This course trains students in Porous Coordination Polymers, also quoted Metal Organic Frameworks (MOFs), define a class of porous materials that is rapidly growing since 1995. These hybrid solids, which are built up from inorganic building units connected through polytopic organic ligands offer a wide variety of composition and structure, and thus properties. This course is also focused on the fine control of electrochemical reactions for producing (nano)materials and nanostructured systems.
Content covered	This course will cover: - the following aspects of MOFs: synthesis, crystal structure, functionalization, porosity and related applications, and structural flexibility. - The electrodeposition techniques: local pH change, decomposing metal complexes, self-oscillating co-deposition, etc. Practical work: Synthesis and characterization of coordination polymers and MOFs
Teaching methods	Classroom courses, tutorials, and labwork
Bibliography	
Prerequisites	Chemistry in solution, acid-base reactions, complexing effect, redox reactions

Nano-microtechnology project

Affiliated TU : Elaboration of (nano)materials 2		
Duration : 20h	Number of ECTS: 2	
Year/semester : M2/S3	Language : English	
Main teacher	Aurélie GIRARD	
Learning Objectives	To understand and to apply the micro(nano)technology processes for producing a micro(nano)electronic device by means of lithography and etching methods and thin film deposition in a clean-room. To learn the principles of measuring DC electrical characteristics of MOS transistors and more generally of micro(nano)electronic devices. To learn and to respect security rules in the clean room.	
Content covered	1. Principle of extracting electrical parameters from the DC electrical characteristics of MOS transistors 2. Security rules in the clean room 3. Practical work (part carried out on the CCMO platform in Rennes, 2.5 days): - Fabrication of an integrated device based MOS technology - DC Electrical characterization of the MOS transistors fabricated in CCMO and extraction of the main SPICE electrical parameters (threshold voltage, channel modulation parameter, mobility, ...)	
Teaching methods	Practical work	
Bibliography		
Prerequisitess	Courses on - Advanced physical processes and on - Micro-Nanoelectronics	

Advanced physical processes

Affiliated TU : Elaboration of (nano)materials 2		
Duration : 12h	Number of ECTS: 1	
Year/semester : M2/S3	Language : English	
Main teacher	Rim ETTOURI	
Learning Objectives	This module covers the principles of the generic stages in the manufacture of microelectronic devices (6 hours). A practical section covers TCAD (Technology Computer Assisted Design) initiation using SILVACO, a professionnal software (6 hours).	
Content convered	1. Micro-Nano-Technology processes - Norms to respect in clean rooms - Lithography - Dry and wet etching - Ion implantation for doping modification - Oxidation - Thin film deposition techniques 2. Initiation to Technology Computer Assisted Design using SILVACO	
Teaching methods		
Bibliography		
Prerequisitess	Courses on - Advanced physical processes and on Micro-Nanoelectronics	

TEACHING UNIT: CHARACTERIZATION OF MATERIALS 2 (3 ECTS)

Advanced microscopy and spectroscopy

Affiliated TU : Elaboration of (nano)materials 2	
Duration : 24h	Number of ECTS : 2
Year/Semester : M2/S3	Language : English
Main teacher	Philippe MOREAU
Learning objectives	Acquire a good knowledge of SPM, TEM, EELS and XPS techniques Be able to determine which technique to use for what purpose in the context of Innovative Materials and Energy Systems
Content covered	1. SPM (Scanning Probe Microscopy) techniques among which AFM, EFM, KPFM.. with detailed knowledge of their physical principles and specific examples 2. TEM (Transmission Electron Microscopy) with a special focus on electron-mater interaction (elastic-inelastic), microscope architecture, image formation and interpretation, electron diffraction 3. EELS (Electron Energy Loss Spectroscopy): principle of the spectrum formation, detectors and qualitative interpretation, basis of quantification and its limitation, mapping 4. XPS (X-Ray Photoelectron Spectroscopy): quantitative analysis with special focus on background removal, attenuation length, charging effect and application to PV samples. Deep work on publications found in literature.
Teaching methods	Face-to-face lectures as well as training on problems. Support of publications. Practicals with special access to high level instruments
Bibliography	
Prerequisitess	Basis of light-electron-particle interaction with matter (bachelor level) Basis of atom and solid state electronic structures (bachelor level)

Advanced X-ray and neutron diffraction

Affiliated TU: Characterization of materials 2	
Duration : 12h	Number of ECTS: 1
Year/semester: M2/S3	Teaching language: English
Main teacher	Olivier HERNANDEZ
Learning objectives	Advanced characterization of solid-state materials: nuclear and magnetic structures by X-ray and neutron diffraction. Use of synchrotron and neutron diffraction/total scattering techniques.
Content covered	**Part 1.** : Production of synchrotron light and neutron beam and comparison of their properties; advanced X-ray and neutron diffraction experiments and structural refinements; total scattering techniques and the pair distribution function. **Part 2.** : Scientific examples, involving mostly transition metal chalcogenides or clusters, illustrating how such structural analyses may lead to a better knowledge of the nuclear or magnetic structure, for a better understanding of the structure-property relationships.
Teaching methods	Slide show lecture; Tutorials in groups
Bibliography	Fundamentals of Crystallography (C. Giacovazzo); Powder Diffraction, Theory and Practice (R.E. Dinnebier, S.J.L. Billinge)
Prerequisites	Bachelor level in Physics and Chemistry

TEACHING UNIT: NANOSCIENCES - QUANTUM MATERIALS - ELECTRONIC DEVICES (6 ECTS)

Nanophysics – Quantum materials

Affiliated TU : Nanosciences – Quantum materials – Electronic devices	
Duration: 24h	Number of ECTS: 2
Year / Semester: M2/S3	Language: English
Main teacher	Jean-Luc DUVAIL
Learning objectives	**Part 1**: Exploration of the new physics that occurs at the nanoscale, emphasizing the electrical properties at the mesoscopic scale and the spin electronics. Particular attention is paid to characteristic physical lengths in comparison with the dimensions of the systems studied. **Part 2**: Exploration of the main quantum materials families, with a focus on properties due to strong correlations in transition metal oxides and chalcogenides. Exploitation for applications such as memory, memristors, artificial synapses.
Content covered	**Part 1:** Mesoscopic physics (12h -J.L. Duvail) I. - Fundamentals and confinement II- Electrical properties at the mesoscopic scale III- Fundamentals concepts in spin polarized transport **Part 2**: Quantum materials (12h - L. Cario, E. Janod) I. Introduction to main families of Quantum materials II. Introduction to strongly correlated materials III. Memories : emerging non-volatile memories IV. Computing paradigm : past, present and future
Teaching methods	Lectures; case studies on articles from the scientific literature
Bibliography	Review articles from the specialized litterature
Prerequisitess	Solid state physics ; cristallography

Micro-nanoelectronics

Affiliated TU : Nanosciences – Quantum materials – Electronic devices	
Duration : 24h	Number of ECTS : 2
Year/semester : M2/S3	Language : English
Main teacher	Ahmed RHALLABI
Learning Objectives	Skills in the electrical properties of CMOS technology and its use in digital and analog applications, Skills in the electrical simulation of basic digital and analog components and functions.
Content convered	Physics of semiconductors and transport phenomena - MOS transistor - Static and Dynamic studies - CMOS technologie: Electrical studies of basic digital and analog functions - Memory technologies - Project on the design of a static memory for reading and writing
Teaching methods	Course, applications and project on CAD of SRAM .
Bibliography	J. Millman and A. Grabel, Microelectronics, McGraw-Hill - International Edition, 1988 P. Molinaro, A. Chriette, Electronique Analogique, Traitement des composants et des circuits, ellipses R. Waser, Nanoelectronics and Information Technology, Wiley-VCH, 2003
Prerequisites	Physic of semiconductors

Nanomaterials

Affiliated TU : Nanosciences – Quantum materials – Electronic devices		
Duration : 24h	Number of ECTS : 2	
Year/semester : M2/S3	Language : English	
Main Teacher	Jean-Luc DUVAIL	
Learning objectives	This Course aims to introduce the main families of 0D, 1D, and 2D nanomaterials by emphasizing the relationship beetween : - the synthesis (relevant parameters), - the nanoparticle morphology (with control at the nanoscale) and structure, - the specific properties due to the nanoscale and to the increase of the surface (interface) - their potential for applications.	
Content covered	**Part A.** Metallic nanoparticules (J.L. Duvail) I. Synthesis and related morphologies II. Plasmonic properties (localized surface plasmon resonance ; surface plasmon polariton) ; other properties III. Applications of functional metallic nanoparticles. **Part B.** Magnetic nanoparticles (J.L. Duvail) I. Magnetic properties of metal and metal oxide nanoparticles II. Applications of functional magnetic nanoparticles. **Part C.** Nanocarbons (C. Ewels) I. Fullerenes (C60,...) II. Carbon nanotubes (CNT) : growth, structure, properties, applications III. Composites and Fibres IV. Graphene: growth, structure, properties, applications V. Nanodiamond and miscelleneous carbons **Part D.** 2D Materials (C. Ewels) I. Production and integration of 2D materials (growth, exfoliation,...) II. X-enes (phosphorene, silicene,...) II. Boron nitride (BN) III. Transition metal dichalcogenides (TMD) IV. MX-enes and 2D oxides **Part E.** Semiconducting and dielectric nanoparticules (S. Perruchas) I. Fabrication, main physical properties and potential applications of quantum dots, 0D nanoparticles, nanorods and nanowires II. Synthesis, functionalisation, optical properties III. Application for energy conversion, displays, bioimagery and biosensing.	
Teaching methods	Lectures; case studies on articles from the scientific literature	
Bibliography	Review articles from the specialized litterature	
Prerequisites	Solid state physics ; crystallography	

TEACHING UNIT : ENERGY SYSTEMS (6 ECTS)

Photovoltaics 2 : New devices

Affiliated TU : Energy systems		
Duration : 28h	Number of ECTS : 2.1	
Year/semester : M2/S3	Language : English	
Main teacher	Nicolas BARREAU	
Learning objectives	Introducing students to thin-film PV technologies for renewable energies. At the end of this course, students will be able to: - understand alternative thin-film technologies to silicon - critically identify the most suitable compounds and architectures for manufacturing a photovoltaic cell - choose the technology best suited to the intended application or use	
Content covered	Thin-film alternatives to silicon: **Part I.** CIGS and CdTe thin-film technologies : Synthesis processes for CIGS and CdTe thin-film materials. Relationships between physico-chemical and electronic properties. Module manufacturing : etching, monolithic integration, innovative architectures. Manufacturing costs. Innovative applications : architectural integration, mobile electronics. Socio-economic impact of inorganic thin-film PV technologies. **Part II.** Hybrid dye-sensitized and organic photovoltaic cells : Operating principles Materials used and their functions Relationship between material properties and photovoltaic performance Large-scale production techniques: inkjet printing and roll-to-roll impregnation Innovative applications : architectural integration, mobile electronics	
Teaching methods	Lectures, tutorials, in-class demonstrations	
Bibliography		
Prerequisites	Principles and Applications	

Electrochemical storage level 2: new devices

Affiliated TU : Energy systems		
Duration : 28h	Nombre d’ECTS : 2.1	
Year/semester : M2-S3	Language : English	
Main teacher	Philippe POIZOT	
Learning objectives	This course trains students in current and future electrochemical energy storage and conversion technologies. At the end of this course, students will be able to: - Describe the operating principle and main electrical characteristics of new electrochemical storage technologies. - Describe and apply advanced electrochemical characterization techniques (potential and/or current control). - Perform simple modeling of electrochemical interfaces (Z-view software). - Collaborate with experts in electrochemical generators.	

Content covered	**1.** Electrochemical energy storage systems : - Introduction to electrode shaping techniques - Advanced electrochemical characterization techniques (PITT, GITT, power measurements) - Future technologies: new electrode materials and devices - Supercapacitors and hybrid systems **2.** Hydrogen vector : - Production, processing and characterization - Storage and distribution **3.** Practical aspects : - Assembly and performance evaluation of semi-commercial devices (batteries and supercapacitors) - Electrochemical impedance spectroscopy and modeling of equivalent circuits (application to fuel cells)
Teaching methods	Classroom courses, tutorials, and labwork
Bibliography	
Prerequisites	Fundamentals of electrochemistry, Butler-Volmer equations, Tafel, Diffusion, Cell assembly, Performance assessment of electrochemical generators

Thermal energy systems

Affiliated TU : Energy systems		
Duration : 24h	Number of ECTS : 1.8	
Year/semester : M2/S3	Language: English	
Main teacher	Xavier PY	
Learning Objectives	At the end of the course, students will be familiar with the main thermal energy systems involved in the energy transition, and with the issues linked to the associated materials in terms of both their properties for use and their environmental impact. They will be able to carry out a materials selection study based on a comprehensive multi-criteria methodology.	
Content convered	The course is dedicated to some of the major thermal energy systems of the energy transition, for which materials-related aspects are crucial. Namely, the systems studied are: thermal energy storages (sensible heat, latent heat, thermochemical), non-concentrated and concentrated solar thermal energy, surface geothermal energy and CO2 capture. The materials involved are studied both for their properties of use and their environmental impact. Particular emphasis is placed not only on material characterization techniques, but also on multi-criteria selection methods. The entire course is also illustrated with current contextual data in terms of material requirements for the energy transition, potential conflicts of use and changes in world markets. Part of the course is dedicated to practical work on the materials and systems under consideration.	
Teaching methods	The training will be based on lectures, practical work on group, critical reading and discussion of documents.	
Bibliography	Students will be invited to follow and read European and international expert reports on the energy transition and related processes (IEA, IPCC, ADEME, etc.). Specific academic publications will also be provided for group reading and discussion.	
Prerequisites	Basic knowledge on energy production, conversion and storage.	

TEACHING UNIT : MODELING 2 (6 ECTS)

Multiphysics modeling 2

Affiliated TU : Modeling 2		
Duration : 24h	Number of ECTS : 2	
Year/Semester : M2/S3	Language : French / English	
Main teacher	Stéphane CUENOT	
Learning objectives	The student will be able to: • master the modeling steps of a simple multiphysics problem • master the optimization of the mesh to ensure the convergence of the numerical solution by controlling the compromise between precision and computation time • know how to structure the numerical resolution steps of a complex multiphysics problem	
Content covered	2D and 3D modeling of simple and complex multiphysics problems Control of boundary conditions, mesh and solvers for coupled physical problems Weak and strong coupling of the physical modules used Control of the convergence of the numerical solution, optimization of the mesh Multi-physics problems solved in stationary, transient and parametric regimes Post-processing and analysis of numerical results.	
Teaching methods	Students work individually on practical multiphysical modeling work, before developing a micro-modeling project in pairs.	
Bibliography		
Prerequisites	Physical and multi-scale modeling	

Quantum mechanical modeling of electronic interactions

Affiliated TU: Modeling 2		
Duration: 24h	Number of ECTS: 2	
Year/semester : M2/S3	Language: English	
Main teacher	Camille LATOUCHE	
Learning Objectives	In this course, the theoretical foundations necessary for understanding, implementing, and interpreting ab initio simulations for molecular and solid materials will be presented, particularly focusing on methods based on wave function (WF) and density functional theory (DFT). Upon completion of this course, the student will be able to: - determine the most appropriate method to study a material and its properties e.g.: simulate absorption spectra in the UV and vibrational spectra) - understand and rationalize observed properties to guide experimentalists towards the synthesis of materials with optimized properties - interpret and analyze modeling results from the scientific literature.	
Content convered	**Part 1:** Quantum modelling of electrons in crystals 1.Reminder: electrons in crystals; reciprocal space 2. Bloch electrons; Born von Karman boundary conditions; Brillouin zone 3. Electronic structure: the tight binding model 4. Electronic correlation: towards magnetism 5. Quantum transport using non equilibrium Green functions **Part 2:** Density Functional Theory 1. Introduction to Quantum modelling in Chemistry and Physics: from HF to DFT 2. Computations: from relaxation to properties 3. How to interpret properties through computations 4. Beyond DFT	
Teaching methods	Lectures (CM), and practical work (TP). A distance project will also be included.	

Bibliography	Introduction to Computational Chemistry, F. Jensen; Modern Quantum Chemistry, A. Szabo and N. Ostlund; Quantum Chemistry, I. N. Levine; Essentials of Computational Chemistry (Theories and Model), C. Cramer
Prerequisites	

Artificial Intelligence for materials discovery and design

Affiliated TU : Modeling 2	
Duration : 24h	Number of ECTS : 2
Year/semester : M2/S3	Language : English
Main teacher	Isabelle BRAEMS-ABBASPOUR
Learning objectives	At the end of this course, students will be able to : - Understand the aims and challenges of AI in materials science - Use material databases, process and analyze these data when searching for a material with given properties - Use tools for data mining, machine learning and deep learning, and optimization (genetic algorithms) - Familiarize themselves with the tools of generative AI - Predict the crystalline structure of a material from its chemical composition
Content covered	Materials informatics is a recent discipline that applies some advanced tools from informatics to materials science and engineering in order to improve efficiently the understanding, use, design, selection, and discovery of materials. It includes combinatorial chemistry, materials property databases, and tools from artificial intelligence (machine learning, deep learning…) to accelerate both the discovery and design of new materials. 1. Introduction to AI, material databases, data mining 2. Machine learning 101 3. Deep learning in materials science 4. Crystal structure prediction for solids and carbon molecules 5. Introduction to generative AI
Teaching methods	Individual learning in the form of practical work directly linked to the course; study of academic research papers
Bibliography	
Prerequisites	

TEACHING UNIT: PREPARING FOR PROFESSIONAL INTEGRATION (4 ECTS)

Innovation, transitions and project management under high uncertainty

Affiliated TU : Preparing for professional integration	
Duration : 21h	Number of ECTS : 3.2
Year/semester : M2/S4	Language : mixed English and French (possibility of using the Omist translation tool)
Main teacher	Mathias GUERINEAU
Learning Objectives	At the end of the course, students will be able to : - Understand local, national and international innovation systems - Adopt a critical and analytical view of technologies - Understand and integrate technological, human and societal issues linked to transitions - Responding to a call for projects - Plan and organize over time - Manage a team in a situation of uncertainty - Use specific project management tools to deal with uncertainty
Content convered	Contemporary project management practices : - organization of research based on calls for projects and the inherent difficulties, - discovery and practice of contemporary project management tools, - discovering agile methods for working under uncertainty, etc. Innovation management in transitions : - the place of technologies in transitions, - dissemination and acceptability of innovations & technologies in society, - taking ecological constraints into account in innovation models. 3 issues are particularly addressed in this course: Defining and managing innovation; The question of spatial anchoring in innovation ecosystems and ; the question of paradigm shifts (growth, ecology, sobriety, etc.) around innovation.
Teaching methods	*Face to face for notions and theories, case studies, debates*
Bibliography	
Prerequisites	

Thematic school

Affiliated TU : Preparing for professional integration	
Duration : h	Number of ECTS : 0.8
Year/semester : M2/S3	Language : English
Main teacher	Jean-Luc Duvail, Philippe Poizot, Xavier Py
Learning Objectives	At the end of the course, students will be able to : - Manage the organization of the day(s) related to the event. - Develop interpersonal skills through interactions with event guests. - Strengthen the ability to work independently.
Content convered	Variable topics
Teaching methods	*Face to face for notions and theories, case studies, debates*
Bibliography	
Prerequisites	

TEACHING UNIT : INTERNSHIP (30 ECTS)

The internship plays an important role in the E-Mat Master's curriculum, and is based on close interaction between research and technological innovation. Students will spend between 4 and 6 months working in a national or international research team or industry.

Mobility of students enrolled in the E-Mat Master's program during the internship :

This GP encourages international mobility for students by making available to them the international network of teacher-researchers from the two partner laboratories.

Students are eligible for a mobility grant of between €500 and €700 per month, depending on the target country. They are also eligible for a €1,000 relocation grant.

Hosting foreign students for internships in our partner laboratories :

Foreign students wishing to do an internship in one of our partner laboratories should send their application, together with their CV and a summary of their areas of interest, to the program coordinators. If the application is deemed admissible, they will be offered an interview to explain their objectives.

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