Course guide
2500017 - MGECNUMENG - Numerical Methods in Engineering

Unit in charge: Barcelona School of Civil Engineering
Teaching unit: 751 - DECA - Department of Civil and Environmental Engineering.

Degree: BACHELOR’S DEGREE IN CIVIL ENGINEERING (Syllabus 2020). (Compulsory subject).

Academic year: 2021 ECTS Credits: 6.0 Languages: English

LECTURER

Coordinating lecturer: JOSE SARRATE RAMOS

Others: JORDI MANYER FUERTES, DAVID MODESTO GALENDE, ESTHER SALA LARDIES, JOSE SARRATE RAMOS

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
14394. Basic knowledge about the use and programming of computers, operating systems, databases and computer programs with engineering application. (Basic training module)

TEACHING METHODOLOGY

The course consists of 2 hours per week of classroom activity (large size group) and 1.6 hours weekly with half the students (medium size group).

The 2 hours in the large size groups are devoted to theoretical lectures, in which the teacher presents the basic concepts and topics of the subject, shows examples and solves exercises.

The 1.6 hours in the medium size groups is devoted to solving practical problems with greater interaction with the students. The objective of these practical exercises is to consolidate the general and specific learning objectives.

The rest of weekly hours devoted to laboratory practice.

Support material in the form of a detailed teaching plan is provided using the virtual campus ATENEA: content, program of learning and assessment activities conducted and literature.
LEARNING OBJECTIVES OF THE SUBJECT


1. Ability to use standard computer tools to solve basic problems (e.g., measurements).
2. Ability to use a numerical analysis program to perform a sensitivity analysis of a problem in which an ordinary differential equation is solved.
3. Ability to solve an engineering problem using numerical techniques.


The desired learning objectives are:

1. To demonstrate knowledge and understanding of the properties and characteristics of basic numerical methods for: solving nonlinear scalar equations; solving linear systems of equations, functional approximation; numerical integration and solving ordinary differential equations.

2. To demonstrate the ability to (thinking skills): understand and formulate numerical procedures in order to solve basic engineering problems and identify appropriate methods for that problem.

3. Demonstrate the ability to (practical skills): understand the practical consequences of the behavior of numerical methods and solutions; logically formulate numerical methods for the computer solution in a programming language (Matlab).

4. Demonstrate the ability to (key skills): study independently, use the resources of the library, use a personal computer for basic programming, take notes efficiently and manage working time.

STUDY LOAD

<table>
<thead>
<tr>
<th>Type</th>
<th>Hours</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours small group</td>
<td>6,0</td>
<td>4.00</td>
</tr>
<tr>
<td>Hours medium group</td>
<td>24,0</td>
<td>16.00</td>
</tr>
<tr>
<td>Self study</td>
<td>84,0</td>
<td>56.00</td>
</tr>
<tr>
<td>Guided activities</td>
<td>6,0</td>
<td>4.00</td>
</tr>
<tr>
<td>Hours large group</td>
<td>30,0</td>
<td>20.00</td>
</tr>
</tbody>
</table>

Total learning time: 150 h
## CONTENTS

### Basics on numerical modeling and programming

**Description:**
- Introduction to modeling
- Introduction to programming in MATLAB.
- Concept and definitions of error (absolute, relative, rounding, truncation, significant digits) and their propagation.

**Specific objectives:**
- Be able to develop simple programs in MATLAB.
- To know the representation of integers and real numbers in a computer.
- To know the concept and definitions of error and understand how they affect the numerical calculation.

**Full-or-part-time:** 28h 47m
- Theory classes: 2h
- Laboratory classes: 10h
- Self study: 16h 47m

### Root finding

**Description:**
- Basic concepts of iterative methods: consistency, linear, superlinear or p-order convergence, asymptotic factor.
- Methods: Newton, secant, Whittaker.
- Solving engineering problems that deal with nonlinear scalar equations.

**Specific objectives:**
- Understand the operation of iterative methods, differentiating them from methods with a finite number of operations.
- To know the properties, advantages and disadvantages of the usual iterative schemes.
- To know how to choose the most appropriate method in each case.
- To know how to analyze, implement and interpret the results of iterative methods.

**Full-or-part-time:** 14h 23m
- Theory classes: 3h
- Laboratory classes: 3h
- Self study: 8h 23m

### Test #1

**Description:**
- Resolution of assessment # 1

**Full-or-part-time:** 4h 48m
- Practical classes: 1h
- Laboratory classes: 1h
- Self study: 2h 48m
Systems of linear equations

Description:
Classification and definitions.
Factorization methods: Crout and Cholesky
Iterative methods: conjugate gradients (equivalence with minimization problem, maximum decrease, conjugate gradients, algorithm, properties)
Solving engineering problems that involve solving systems of linear equations

Specific objectives:
To know the classification of methods for solving systems of linear equations.
To know the range of applicability of each method and its computational advantages and disadvantages.
To know the details of the analysis of the conjugate gradient method and be able to implement it correctly.
To know how to implement the resolution methods presented.
To know how to identify the practical influence of the number of condition, preconditioners...

Full-or-part-time: 24h
Theory classes: 4h
Laboratory classes: 6h
Self study : 14h

Functional approximation

Description:
General approach: types and criteria of approximation
Polynomial interpolation
Least squares
Sectional approximation
Solving engineering problems involving the approximation of functions and data

Specific objectives:
To demonstrate knowledge and understanding of:
- the criteria and types of functional approximation and their advantages and disadvantages,
- Lagrange interpolation and its error and an ability to use it,
- the least squares problem, namely to deduce the normal equations and understand the approximation orthogonality,
- splines.

To demonstrate an ability to use and code some intrinsic functions to approximate a data set.
Be able to solve functional approximation problems

Full-or-part-time: 19h 12m
Theory classes: 4h
Laboratory classes: 4h
Self study : 11h 12m

Test #2

Description:
Resolution of assessment #2

Full-or-part-time: 7h 11m
Practical classes: 1h
Laboratory classes: 2h
Self study : 4h 11m
Numerical integration

**Description:**
- General approach, eg with trapezoidal rule
- Definition of order of a quadrature
- Quadrature classification
- Newton-Cotes formulas
- Gauss quadrature
- Composite formulae

Analyze and discuss convergence of the following quadratures:
- Newton-Cotes and Gauss-Legendre as the number of integration points increases,
- composite formulae as the number of intervals increases.

Solving engineering problems involving the evaluation of integrals numerically

**Specific objectives:**
- demonstrate knowledge and understanding of:
  - The basis of numerical integration,
  - The classification of quadratures,
  - The basis of the Newton-Cotes and Gaussian quadratures,
  - The composite quadratures and their advantages and disadvantages.

To demonstrate an ability to:
- Define a quadrature if the integration points are given,
- Use Newton-Cotes and Gaussian quadratures, choosing the correct one in terms of accuracy and computational cost,
- Use composite quadratures.

To demonstrate an ability to apply all the concepts of numerical integration to the FEM.

To demonstrate an ability to implement an algorithm for numerical integration.

To demonstrate an ability to implement an algorithm for composite formulae.

**Full-or-part-time:** 19h 12m
- Theory classes: 4h
- Laboratory classes: 4h
- Self study: 11h 12m
Modelling with Ordinary Differential Equations (ODEs)

Description:
General approach: reduction to first order, initial value (IVP), boundary value (BVP) or eigenvalue problem, existence and uniqueness theorem.
Methods based on the approximation of the derivative: Euler, backward Euler.
Truncation error, consistency, local and global error, order, absolute stability.
Single step methods (Runge-Kutta) methods: second and fourth order.
Solving engineering problems described using ODEs

Specific objectives:
Understand the concept of well-posed initial value problems (IVP).
Ability to identify and classify a problem of ODEs (in any order and dimension).
Ability to rewrite high-order ODEs as a system of first order ODEs.
Ability to identify Initial Value Problems (IVP) and Boundary Problem (BP).
Understand the concepts of convergence, order of convergence and absolute stability.
Knowledge of the basic properties of Runge-Kutta methods. Understand the general form and be able to apply them. Ability to identify explicit, semi-implicit and implicit methods.
To demonstrate an ability to model an engineering problem as a system of ODEs.
To demonstrate an ability to use a library for the numerical solution of ODEs.
Modelling and numerical resolution of engineering problems governed by ODEs.

Full-or-part-time: 21h 36m
Theory classes: 4h
Laboratory classes: 5h
Self study : 12h 36m

Test #3

Description:
Test #3

Full-or-part-time: 4h 48m
Laboratory classes: 2h
Self study : 2h 48m

GRADING SYSTEM

The mark of the course is obtained from the ratings of continuous assessment and their corresponding laboratories and/or classroom computers.
Continuous assessment consist in several activities, both individually and in group, of additive and training characteristics, carried out during the year (both in and out of the classroom).
The teachings of the laboratory grade is the average in such activities.
The evaluation tests consist of a part with questions about concepts associated with the learning objectives of the course with regard to knowledge or understanding, and a part with a set of application exercises.

EXAMINATION RULES.

Will be discussed in class.
BIBLIOGRAPHY

Basic:

Complementary: