Module Handbook

Master Program
Data Science
60 ECTS

Master of Science (M.Sc.)

Distance Learning

Modulhandbuch_FI-MADS-60_Data Science_SGo_19.09.2019

This module handbook contains information about the topical issues and the organisation of the Master Program “Master Data Science“ (60 ECTS)”.

In particular, it contains

- ***Administrative facts***
  - ⇨ module-/course number
  - ⇨ module-/course titles
  - ⇨ duration of modules/courses
  - ⇨ ECTS-credits
  - ⇨ Module director

- ***Academic approaches***
  - ⇨ type of lecture
  - ⇨ prerequisites, topical links to other modules
  - ⇨ language of instruction
  - ⇨ course objectives
  - ⇨ course content, course literature, instructional methods

- ***Student affairs***
  - ⇨ course outcomes
  - ⇨ workload structured by contact hours and individual studies

- ***Examination issues***
  - ⇨ number and type of assessments
  - ⇨ requirements for participation in final assessments
  - ⇨ modular weightings within the final master mark

Contents

Module DLMDSAS

Advanced Statistics

5 ECTS

Minimum duration of the module:	**1 semester**
Admission requirements:	Advanced Mathematics (DLMDSAM01)

Module Description

<table>
<tr><td>Module Title:</td><td colspan="2">Advanced Statistics</td></tr>
<tr><td>Module No.:
DLMDSAS</td><td>Semester / Term:
1st semester</td><td>Duration:
Minimum 1 semester</td></tr>
<tr><td>Module Type(s):</td><td>Compulsory</td><td>Regularly Offered in:
WS / SS</td></tr>
<tr><td colspan="2">Workload: 150 h</td><td>Credit Points: 5</td></tr>
<tr><td colspan="2">Admission Requirements:
▪ Advanced Mathematics (DLMDSAM01)</td><td>Language of Instruction:
English</td></tr>
<tr><td colspan="2">Contributing Courses to Module:
▪ Advanced Statistics (DLMDSAS01)</td><td>Workload:
Self-study: 90 h
Self-examination: 30 h
Tutorials: 30 h</td></tr>
<tr><td colspan="2">Course Coordinator(s) / Tutor(s):
Please see the current list of tutors on the Learning Management System.</td><td>Module Director:
Prof. Dr. Marco de Pinto</td></tr>
<tr><td colspan="2">References to Other Programs:
▪ Master Artificial Intelligence (120 ECTS)</td><td>References to Other Modules in the Program:
▪ Advanced Statistics
▪ Deep Learning</td></tr>
</table>

Qualification and Educational Objectives of the Module: On successful completion of this module, students will be able to: ▪ understand the fundamental building blocks of statistics. ▪ analyze stochastic data in terms of the underlying probability distributions. ▪ utilize Bayesian statistics techniques. ▪ summarize the properties of observed data using descriptive statistics. ▪ apply data visualization techniques to illustrate the behavior of observed data. ▪ evaluate model parameters using parameter estimation techniques. ▪ create hypothesis tests to discriminate between several model classes.		
Learning Content of the Module: ▪ Introduction to statistics ▪ Important probability distributions and their applications ▪ Bayesian statistics ▪ Descriptive statistics ▪ Data visualization ▪ Parameter estimation ▪ Hypothesis tests		
Teaching Methods:	See the contributing course outline	
Literature:	See the contributing course outline	
Percentage of the Module Grade Relative to the Final Grade for the Program: 5 ECTS of 60 ECTS = 8.33%	**Prerequisites to Qualify for Assessment:** See course outline	**Assessment:** <u>DLMDSAS01:</u> Exam, 90 min. (100%)

<table>
<tr><td>Course No.:
DLMDSAS01</td><td>Course Title:
Advanced Statistics</td><td>Hours Total: 150

Credit Points: 5</td></tr>
<tr><td colspan="2">Course Type: Compulsory
Course Availability: In each semester
Course Duration: Minimum 1 semester</td><td>Admission Requirements:
Please see module description.</td></tr>
<tr><td colspan="2">Course Coordinator / Instructor:
See current list of tutors in the Learning Management System.</td><td>References to Other Modules:
Please see module description.</td></tr>
</table>

Course Description:

Nearly all processes in nature and technical or scientific scenarios are not deterministic but stochastic. Therefore, these processes must be described in terms of probabilities and probability density distributions.

After defining and introducing the fundamental concepts of statistics, the course will cover important probability distributions and their prevalence in application scenarios; discuss descriptive techniques to summarize and visualize data effectively; and discuss the Bayesian approach to statistics.

Estimating parameters is a key ingredient in optimizing data models, and the course will give a thorough overview of the most important techniques.

Hypothesis testing is a crucial aspect in establishing the observation of new effects and determination of the significance of statistical effects. Special focus will be given to the correct interpretation of p-Values and the correct procedure for multiple hypothesis tests.

Course Objectives and Outcome:

On successful completion of this course, students will be able to:

- understand the fundamental building blocks of statistics.
- analyze stochastic data in terms of the underlying probability distributions.
- utilize Bayesian statistics techniques.
- summarize the properties of observed data using descriptive statistics.
- apply data visualization techniques to design graphics that illustrate the behavior of observed data.
- evaluate model parameters using parameter estimation techniques.
- create hypothesis tests to discriminate between several model classes.

Teaching Methods:

The learning materials include printed and online course books, vodcasts, online knowledge tests, podcasts, online tutorials, and case studies. This range of learning materials is offered to students so they can study at a time, place, and pace that best suits their circumstances and individual learning style.

Course Content:

1. **Introduction to Statistics**
   1.1. Random Variables
   1.2. Kolmogorov Axioms
   1.3. Probability Distributions
   1.4. Decomposing probability distributions
   1.5. Expectation Values and Moments
   1.6. Central Limit Theorem
   1.7. Sufficient Statistics
   1.8. Problems of Dimensionality
   1.9. Component Analysis and Discriminants
2. **Important Probability Distributions and their Applications**
   2.1. Binomial Distribution
   2.2. Gauss or Normal Distribution
   2.3. Poisson and Gamma-Poisson Distribution
   2.4. Weibull Distribution
3. **Bayesian Statistics**
   3.1. Bayes' Rule
   3.2. Estimating the Prior, Benford's Law, Jeffry's Rule
   3.3. Conjugate Prior
   3.4. Bayesian & Frequentist Approach
4. **Descriptive Statistics**
   4.1. Mean, Median, Mode, Quantiles
   4.2. Variance, Skewness, Kurtosis
5. **Data Visualization**
   5.1. General Principles of Dataviz/Visual Communication
   5.2. 1D, 2D Histograms
   5.3. Box Plot, Violin Plot
   5.4. Scatter Plot, Scatter Plot Matrix, Profile Plot
   5.5. Bar Chart
6. **Parameter Estimation**
   6.1. Maximum Likelihood
   6.2. Ordinary Least Squares
   6.3. Expectation Maximization (EM)
   6.4. Lasso and Ridge Regularization
   6.5. Propagation of Uncertainties
7. **Hypothesis Test**
   7.1. Error of 1st and 2nd Kind
   7.2. Multiple Hypothesis Tests
   7.3. p-Value

Literature: ▪ Bishop, C. (2007). *Pattern recognition and machine learning* (2nd ed.). Singapore: Springer. ▪ Bruce, P., & Bruce, A. (2017). *Statistics for data scientists: 50 essential concepts*. Sebastopol, CA: O'Reilley Publishing. ▪ Downey, A. (2013). *Think Bayes.* Sebastopol, CA: O'Reilley Publishing. ▪ Downey, A. (2014). *Think stats.* Sebastopol, CA: O'Reilley Publishing. ▪ McKay, D. (2003). *Information theory, inference and learning algorithms*. Cambridge: Cambridge University Press. ▪ Reinhart, A. (2015). *Statistics done wrong*. San Francisco, CA: No Starch Press. A current list with course-specific compulsory reading, as well as references to further literature, is stored in the Learning Management System.	
Prerequisites to Qualify for Assessment:	▪ Depending on the course: Completion of online knowledge tests (approx. 15 minutes per unit, pass / not pass) — x
Assessment:	▪ Exam, 90 min.
Student Workload (in hours): 150	Self-study: 90 Self-testing: 30 Tutorials: 30

Module DLMDSUCE

Use Case and Evaluation

5 ECTS

Minimum duration of the module:	**1 semester**
Admission requirements:	Advanced Mathematics (DLMDSAM01)

Module Description

<table>
<tr><td>Module Title:</td><td colspan="2">Use Case and Evaluation</td></tr>
<tr><td>Module No.:
DLMDSUCE</td><td>Semester / Term:
1st semester</td><td>Duration:
Minimum 1 semester</td></tr>
<tr><td>Module Type(s):</td><td>Compulsory</td><td>Regularly Offered in:
WS / SS</td></tr>
<tr><td colspan="2">Workload: 150 h</td><td>Credit Points: 5</td></tr>
<tr><td colspan="2">Admission Requirements:
▪ Advanced Mathematics (DLMDSAM01)</td><td>Language of Instruction:
English</td></tr>
<tr><td colspan="2">Contributing Courses to Module:
▪ Use Case and Evaluation (DLMDSUCE01)</td><td>Workload:
Self-study: 110 h
Self-examination: 20 h
Tutorials: 20 h</td></tr>
<tr><td colspan="2">Course Coordinator(s) / Tutor(s):
Please see the current list of tutors on the Learning Management System.</td><td>Module Director:
N.N. Professur für Artificial Intelligence</td></tr>
<tr><td colspan="2">References to Other Programs:
▪ Master Artificial Intelligence (120 ECTS)</td><td>References to Other Modules in the Program:
▪ Project: Data Science Use Case
▪ Seminar: Current Topics in Data Science</td></tr>
</table>

Qualification and Educational Objectives of the Module:

On successful completion of this module, students will be able to:

- analyze use cases and their requirements regarding the project objectives.
- apply common metrics to evaluate predictions.
- evaluate key performance indicators to asses projects from a business perspective.
- create monitoring tools that can be used to constantly evaluate the status quo of a project.
- understand common fallacies and how to avoid them.

Learning Content of the Module:

- Use case evaluation
- Model-centric evaluation
- Business-centric evaluation
- Monitoring
- Avoiding common fallacies
- Change management

Teaching Methods:	See the contributing course outline
Literature:	See the contributing course outline

Percentage of the Module Grade Relative to the Final Grade for the Program:	**Prerequisites to Qualify for Assessment:**	**Assessment:**
5 ECTS of 60 ECTS = 8.33%	See course outline	DLMDSUCE01: Oral Assignment (100%)

<table>
<tr><td rowspan="2">Course No.:
DLMDSUCE01</td><td rowspan="2">Course Title:
Use Case and Evaluation</td><td>Hours Total: 150</td></tr>
<tr><td>Credit Points: 5</td></tr>
<tr><td colspan="2">Course Type: Compulsory
Course Availability: In each semester
Course Duration: Minimum 1 semester</td><td>Admission Requirements:
Advanced Mathematics (DLMDSAM01)</td></tr>
<tr><td colspan="2">Course Coordinator / Instructor:
See current list of tutors in the Learning Management System.</td><td>References to Other Modules:
Please see module description.</td></tr>
<tr><td colspan="3">Course Description:

The evaluation and definition of use cases is the fundamental groundwork from which the projects can be defined. This does not only include the scope and technical requirements of a project but also how value can be derived from the project.

A crucial aspect is the definition of what makes a project successful, both in terms of a technical evaluation as well as a business centric perspective and how the status quo can be monitored effectively during the progress of a project.

The course also discusses how to avoid common fallacies and understand the implications of introducing data-driven decisions into traditional management structures.</td></tr>
<tr><td colspan="3">Course Objectives and Outcome:

On successful completion of this course, students will be able to:
▪ analyze use cases and their requirements regarding the project objectives.
▪ apply common metrics to evaluate predictions.
▪ evaluate key performance indicators to asses projects from a business perspective.
▪ create monitoring tools that can be used to constantly evaluate the status quo of a project.
▪ understand common fallacies and how to avoid them.</td></tr>
<tr><td colspan="3">Teaching Methods:

The learning materials include printed and online course books, vodcasts, online knowledge tests, podcasts, online tutorials, and case studies. This range of learning materials is offered to students so they can study at a time, place, and pace that best suits their circumstances and individual learning style.</td></tr>
</table>

Course Content:

1. **Use Case Evaluation**
   1.1. Identification of Use Cases
   1.2. Specifying Use Case Requirements
   1.3. Data Sources and Data Handling Classification
2. **Model-centric Evaluation**
   2.1. Common Metrics for Regression and Classification
   2.2. Visual Aides
3. **Business-centric Evaluation**
   3.1. Cost Function and Optimal Point Estimators
   3.2. Evaluation Using KPIs
   3.3. A/B Test
4. **Monitoring**
   4.1. Visual Monitoring Using Dashboards
   4.2. Automated Reporting and Alerting
5. **Avoiding Common Fallacies**
   5.1. Cognitive Biases
   5.2. Statistical Effects
   5.3. Change Management: Transformation to a Data-driven Company

Literature:

- Few, S. (2013). *Information dashboard design: Displaying data for at-a-glance monitoring* (2nd ed.). Burlingame, CA: Analytics Press.
- Gilliland, M., Tashman, L., & Sglavo, U. (2016). *Business forecasting: Practical problems and solutions*. Hoboken, NJ: John Wiley & Sons.
- Hyndman, R. (2018). *Forecasting: Principles and practices* (2nd ed.). OTexts.
- Kahneman, D. (2012). *Thinking, fast and slow*. London: Penguin.
- Parmenter, D. (2015). *Key Performance Indicators (KPI): Developing, implementing, and using winning KPIs* (3rd ed.). Hoboken, NJ: John Wiley & Sons.

A current list with course-specific compulsory reading, as well as references to further literature, is stored in the Learning Management System.

Prerequisites to Qualify for Assessment:	▪ Depending on the course: Completion of online knowledge tests (approx. 15 minutes per unit, pass / not pass)	x
Assessment:	▪ Oral Assignment	
Student Workload (in hours): 150	Self-study: 110 Self-testing: 20 Tutorials: 20	

Module DLMDSSCTDS

Seminar: Current Topics in Data Science

5 ECTS

Minimum duration of the module: **1 semester**

Admission requirements: **None**

Module Description

<table>
<tr><td>Module Title:</td><td colspan="2">Seminar: Current Topics in Data Science</td></tr>
<tr><td>Module No.:
DLMDSSCTDS</td><td>Semester / Term:
1st semester</td><td>Duration:
Minimum 1 semester</td></tr>
<tr><td>Module Type(s):</td><td>Compulsory</td><td>Regularly Offered in:
WS / SS</td></tr>
<tr><td colspan="2">Workload: 150 h</td><td>Credit Points: 5</td></tr>
<tr><td colspan="2">Admission Requirements:
None</td><td>Language of Instruction:
English</td></tr>
<tr><td colspan="2">Contributing Courses to Module:
▪ Seminar: Current Topics in Data Science (DLMDSSCTDS01)</td><td>Workload:
Self-study: 120 h
Self-examination: -- h
Tutorials: 30 h</td></tr>
<tr><td colspan="2">Course Coordinator(s) / Tutor(s):
Please see the current list of tutors on the Learning Management System.</td><td>Module Director:
N.N. Professur für Data Science/AI</td></tr>
<tr><td colspan="2">References to Other Degree Programs:
▪ None</td><td>References to Other Modules in this Degree Program:
▪ Use Case and Evaluation
▪ Deep Learning</td></tr>
</table>

Qualification and Educational Objectives of the Module:

On successful completion of this module, students will be able to:

- identify current research trends and topics in data science.
- outline a selected topic in the form of a written essay.
- explain relevant assumptions and design choices pertaining to the topic of choice.
- relate the chosen topic to comparable approaches.
- name and describe potential applications for the chosen topic's concepts.

Learning Content of the Module:

In this module, students will reflect on current developments in data science. To this end, pertinent topics will be introduced via articles, that are then critically evaluated by the students in the form of a written essay.

A current list of topics is located in the Learning Management System.

Teaching Methods:	See the contributing course outline
Literature:	See the contributing course outline

Percentage of the Module Grade Relative to the Final Grade for the Program:	**Prerequisites to Qualify for Assessment:**	**Assessment:**
5 ECTS of 60 ECTS = 8.33%	See course outline	DLMDSSCTDS01: Written Assessment: Research Essay (100%)

<table>
<tr><td>Course No.:
DLMDSSCTDS01</td><td>Course Title:
Seminar: Current Topics in Data Science</td><td>Hours Total: 150

Credit Points: 5</td></tr>
<tr><td colspan="2">Course Type: Compulsory
Course Availability: In each semester
Course Duration: Minimum 1 semester</td><td>Admission Requirements:
None</td></tr>
<tr><td colspan="2">Course Coordinator / Instructor:
See current list of tutors in the Learning Management System.</td><td>References to Other Modules:
Please see module description.</td></tr>
<tr><td colspan="3">Course Description:

The theory and applications of data science are constantly evolving, with new models and model variations being proposed at a steady rate. Innovative methodological approaches as well as fresh application possibilities are also being continuously developed. This course aims to familiarize the students with the current trends in this rapidly-changing environment. The students learn to independently analyze selected topics and case studies and link them with well-known concepts, as well as critically question and discuss them.</td></tr>
<tr><td colspan="3">Course Objectives and Outcome:

On successful completion of this course, students will be able to:
identify current research trends and topics in data science.
outline a selected topic in the form of a written essay.
explain relevant assumptions and design choices pertaining to the topic of choice.
relate the chosen topic to comparable approaches.
name and describe potential applications for the chosen topic's concepts.</td></tr>
<tr><td colspan="3">Teaching Methods:

The learning materials include printed and online course books, vodcasts, online knowledge tests, podcasts, online tutorials, and case studies. This range of learning materials is offered to students so they can study at a time, place, and pace that best suits their circumstances and individual learning style.</td></tr>
</table>

Course Content:

The seminar covers current topics in data science. Each participant must write a seminar paper on a topic assigned to him/her.

Literature:

- Bishop, C. M. (2016). Pattern recognition and machine learning. New York, NY: Springer.
- James, G., Witten, D., Hastie, T., & Tibshirani, R. (2017). *Introduction to statistical learning*. New York, NY: Springer.
- Kirk, M. (2017). Thoughtful machine learning with Python. Sebastopol, CA: O'Reilly.
- Kleppmann, M. (2017). *Designing data-intensive applications: The big ideas behind reliable, scalable, and maintainable systems.* Sebastopol, CA: O'Reilly.

A current list with course-specific compulsory reading, as well as references to further literature, is stored in the Learning Management System.

Prerequisites to Qualify for Assessment:	▪ Depending on the course: Completion of online knowledge tests (approx. 15 minutes per unit, pass / not pass) ☐
Assessment:	▪ Written Assessment: Research Essay
Student Workload (in hours): 150	Self-study: 120 Self-testing: -- Tutorials: 30

Module DLMDSML

Machine Learning

5 ECTS

Minimum duration of the module: **1 semester**

Admission requirements: Advanced Mathematics (DLMDSAM01)
Programming with Python (DLMDSPWP01)

Module Description

Module Title:	Machine Learning	
Module No.: DLMDSML	**Semester / Term:** 1^{st} semester	**Duration:** Minimum 1 semester
Module Type(s):	Compulsory	**Regularly Offered in:** WS / SS
Workload: 150 h		**Credit Points:** 5
Admission Requirements: ▪ Advanced Mathematics (DLMDSAM01) ▪ Programming with Python (DLMDSPWP01)		**Language of Instruction:** English
Contributing Courses to Module: ▪ Machine Learning (DLMDSML01)		**Workload:** Self-study: 90 h Self-examination: 30 h Tutorials: 30 h
Course Coordinator(s) / Tutor(s): Please see the current list of tutors on the Learning Management System.		**Module Director:** N.N. Online Dozent für Machine Learning
References to Other Degree Programs: ▪ Master Artificial Intelligence (120 ECTS)		**References to Other Modules in this Degree Program:** ▪ Deep Learning ▪ Advanced Statistics

Qualification and Educational Objectives of the Module:

On successful completion of this module, students will be able to:

- know the different machine learning model classes.
- comprehend the difference between supervised, unsupervised, and reinforcement learning methods.
- understand common machine learning models.
- analyze trade-offs in the application of different models.
- appropriately choose machine learning models according to a given task.

Learning Content of the Module:

- Supervised, unsupervised, and reinforcement learning approaches
- Regression and classification learning problems
- Estimation of functional dependencies via regression techniques
- Data clustering
- Support vector machines, large margin classification
- Decision tree learning

Teaching Methods: See the contributing course outline

Literature: See the contributing course outline

Percentage of the Module Grade Relative to the Final Grade for the Program:	**Prerequisites to Qualify for Assessment:**	**Assessment:**
5 ECTS of 60 ECTS = 8.33%	See course outline	DLMDSML01: Exam, 90 min. (100%)

Course No.: DLMDSML01	Course Title: Machine Learning	Hours Total: 150 Credit Points: 5
Course Type: Compulsory **Course Availability:** In each semester **Course Duration:** Minimum 1 semester		**Admission Requirements:** Please see module description.
Course Coordinator / Instructor: See current list of tutors in the Learning Management System.		**References to Other Modules:** Please see module description.

Course Description:

Machine learning is a field of scientific study concerned with algorithmic techniques that enable machines to learn performance on a given task via the discovery of patterns or regularities in exemplary data. Consequently, its methods commonly draw upon a statistical basis in conjunction with the computational capabilities of modern computing hardware.

This course aims to acquaint the student with the main branches of machine learning and provide a thorough introduction to the most widely used approaches and methods in this field.

Course Objectives and Outcome:

On successful completion of this course, students will be able to:

- know different machine learning model classes.
- comprehend the difference between supervised, unsupervised, and reinforcement learning methods.
- understand common machine learning models.
- analyze trade-offs in the application of different models.
- appropriately choose machine learning models according to a given task.

Teaching Methods:

The learning materials include printed and online course books, vodcasts, online knowledge tests, podcasts, online tutorials, and case studies. This range of learning materials is offered to students so they can study at a time, place, and pace that best suits their circumstances and individual learning style.

Course Content:

1. **Introduction to Machine Learning**
   1.1. Regression & Classification
   1.2. Supervised & Unsupervised Learning
   1.3. Reinforcement Learning
2. **Clustering**
   2.1. Introduction to clustering
   2.2. K-Means
   2.3. Expectation Maximization
   2.4. DBScan
   2.5. Hierarchical Clustering
3. **Regression**
   3.1. Linear & Non-linear Regression
   3.2. Logistic Regression
   3.3. Quantile Regression
   3.4. Multivariate Regression
   3.5. Lasso & Ridge Regression
4. **Support Vector Machines**
   4.1. Introduction to Support Vector Machines
   4.2. SVM for Classification
   4.3. SVM for Regression
5. **Decision Trees**
   5.1. Introduction to Decision Trees
   5.2. Decision Trees for Classification
   5.3. Decision Trees for Regression
6. **Genetic Algorithms**
   6.1. Introduction to Genetic Algorithms
   6.2. Applications of Genetic Algorithms

Literature:

- Bishop, C. M. (2011). *Pattern recognition and machine learning*. New York, NY: Springer.
- Efron, B., & Hastie, T. (2016). *Computer age statistical inference*. Cambridge: Cambridge University Press.
- Muller, A. C., & Guido, S. (2016). *Introduction to machine learning with Python*. Sebastopol, CA: O'Reilly.
- VanderPlas, J. (2017). *Python data science handbook*. Sebastopol, CA: O'Reilly Publishing.

A current list with course-specific compulsory reading, as well as references to further literature, is stored in the Learning Management System.		
Prerequisites to Qualify for Assessment:	▪ Depending on the course: Completion of online knowledge tests (approx. 15 minutes per unit, pass / not pass)	x
Assessment:	▪ Exam, 90 min.	
Student Workload (in hours): 150	Self-study: 90 Self-testing: 30 Tutorials: 30	

Module DLMDSDL

Deep Learning

5 ECTS

Minimum duration of the module: **1 semester**

Admission requirements: Advanced Mathematics (DLMDSAM01)
Programming with Python (DLMDSPWP01)
Machine Learning (DLMDSML01)

Module Description

Module Title:	Deep Learning	
Module No.: DLMDSDL	**Semester / Term:** 1^{st} semester	**Duration:** Minimum 1 semester
Module Type(s):	Compulsory	**Regularly Offered in:** WS / SS
Workload: 150 h		**Credit Points:** 5
Admission Requirements: ▪ Advanced Mathematics (DLMDSAM01) ▪ Programming with Python (DLMDSPWP01) ▪ Machine Learning (DLMDSML01)		**Language of Instruction:** English
Contributing Courses to Module: ▪ Deep Learning (DLMDSDL01)		**Workload:** Self-study: 110 h Self-examination: 20 h Tutorials: 20 h
Course Coordinator(s) / Tutor(s): Please see the current list of tutors on the Learning Management System.		**Module Director:** Prof. Dr. Thomas Zöller
References to Other Degree Programs: ▪ Master in Artificial Intelligence (120 ECTS)		**References to Other Modules in this Degree Program:** ▪ Advanced Statistics ▪ Machine Learning

Qualification and Educational Objectives of the Module: On successful completion of this module, students will be able to: ▪ comprehend the fundamental building blocks of neural networks. ▪ understand concepts in deep learning. ▪ analyze the relevant deep learning architecture in a wide range of application scenarios. ▪ create deep learning models. ▪ utilize alternative methods to train deep learning models.
Learning Content of the Module: ▪ Introduction to neural networks and deep earning ▪ Network architectures ▪ Neural network training ▪ Alternative training methods ▪ Further network architectures

Teaching Methods:	See the contributing course outline
Literature:	See the contributing course outline

Percentage of the Module Grade Relative to the Final Grade for the Program:	**Prerequisites to Qualify for Assessment:**	**Assessment:**
5 ECTS of 60 ECTS = 8.33%	See course outline	<u>DLMDSDL01:</u> Oral Assignment (100%)

Course No.: DLMDSDL01	**Course Title:** Deep Learning	**Hours Total:** 150 **Credit Points:** 5
Course Type: Compulsory **Course Availability:** In each semester **Course Duration:** Minimum 1 semester		**Admission Requirements:** Please see module description.
Course Coordinator / Instructor: See current list of tutors in the Learning Management System.		**References to Other Modules:** Please see module description.

Course Description:

Neural networks and deep learning approaches have revolutionized the fields of data science and artificial intelligence in recent years, and applications built on these techniques have reached or surpassed human performance in many specialized applications.

After a short review of the origins of neural networks and deep learning, this course will cover the most common neural network architectures and discuss in detail how neural networks are trained using dedicated data samples, avoiding common pitfalls such as overtraining.

The course includes a detailed overview of alternative methods to train neural networks and further network architectures which are relevant in a wide range of specialized application scenarios.

Course Objectives and Outcome:

On successful completion of this course, students will be able to:

- comprehend the fundamental building blocks of neural networks.
- understand concepts in deep learning.
- analyze the relevant deep learning architecture in a wide range of application scenarios.
- create deep learning models.
- utilize alternative methods to train deep learning models.

Teaching Methods:

The learning materials include printed and online course books, vodcasts, online knowledge tests, podcasts, online tutorials, and case studies. This range of learning materials is offered to students so they can study at a time, place, and pace that best suits their circumstances and individual learning style.

Course Content:

1. **Introduction to Neural Network and Deep Learning**
    1.1. The Biological Brain
    1.2. Perceptron and Multi-Layer Perceptrons
2. **Network Architectures**
    2.1. Feed-Forward Networks
    2.2. Convolutional Networks
    2.3. Recurrent Networks, Memory Cells and LSTMs
3. **Neural Network Training**
    3.1. Weight Initialization and Transfer Function
    3.2. Backpropagation and Gradient Descent
    3.3. Regularization and Overtraining
4. **Alternative Training Methods**
    4.1. Attention
    4.2. Feedback Alignment
    4.3. Synthetic Gradients
    4.4. Decoupled Network Interfaces
5. **Further Network Architectures**
    5.1. Generative Adversarial Networks
    5.2. Autoencoders
    5.3. Restricted Boltzmann Machines
    5.4. Capsule Networks
    5.5. Spiking Networks

Literature:

- Chollet, F. (2017). *Deep learning with Python.* Shelter Island, NY: Manning.
- Efron, B., & Hastie, T. (2016). *Computer age statistical inference.* Cambridge: Cambridge University Press.
- Geron, A. (2017). *Hands-on machine learning with Scikit-Learn and TensorFlow.* Boston, MA: O'Reilly Publishing.
- Goodfellow, I., Bengio, Y., & Courville, A. (2016). *Deep learning.* Boston, MA: MIT Press.
- Russel, S., & Norvig, P. (2010). *Artificial intelligence – A modern approach* (3rd ed.). Essex: Pearson.

A current list with course-specific compulsory reading, as well as references to further literature, is stored in the Learning Management System.

Prerequisites to Qualify for Assessment:	▪ Depending on the course: Completion of online knowledge tests (approx. 15 minutes per unit, pass / not pass)	x
Assessment:	▪ Oral Assignment	
Student Workload (in hours): 150	Self-study: 110 Self-testing: 20 Tutorials: 20	

Module DLMDSME

Case Study: Model Engineering

5 ECTS

Minimum duration of the module: **1 semester**

Admission requirements:

Advanced Mathematics (DLMDSAM01)
Advanced Statistics (DLMDSAS01)
Programming with Python (DLMDSPWP01)
Machine Learning (DLMDSML01)
Deep Learning (DLMSDL01)

Module Description

<table>
<tr><td>Module Title:</td><td colspan="2">Case Study: Model Engineering</td></tr>
<tr><td>Module No.:
DLMDSME</td><td>Semester / Term:
1st semester</td><td>Duration:
Minimum 1 semester</td></tr>
<tr><td>Module Type(s):</td><td>Compulsory</td><td>Regularly Offered in:
WS / SS</td></tr>
<tr><td colspan="2">Workload: 150 h</td><td>Credit Points: 5</td></tr>
<tr><td colspan="2">Admission Requirements:
▪ Advanced Mathematics (DLMDSAM01)
▪ Advanced Statistics (DLMDSAS01)
▪ Programming with Python (DLMDSPWP01)
▪ Machine Learning (DLMDSML01)
▪ Deep Learning (DLMSDL01)</td><td>Language of Instruction:
English</td></tr>
<tr><td colspan="2">Contributing Courses to Module:
▪ Case Study: Model Engineering (DLMDSME01)</td><td>Workload:
Self-study: 110 h
Self-examination: 20 h
Tutorials: 20 h</td></tr>
<tr><td colspan="2">Course Coordinator(s) / Tutor(s):
Please see the current list of tutors on the Learning Management System.</td><td>Module Director:
Dr. Leonardo Riccardi</td></tr>
<tr><td colspan="2">References to Other Degree Programs:
▪ None</td><td>References to Other Modules in this Degree Program:
▪ Advanced Statistics
▪ Machine Learning
▪ Deep Learning</td></tr>
</table>

Qualification and Educational Objectives of the Module:
On successful completion of this module, students will be able to: ▪ understand current data science methodologies. ▪ evaluate the quality of the data used in data science projects. ▪ create new features from raw data. ▪ apply feature selection techniques. ▪ make predictive models using data science techniques. ▪ identify common fallacies and know how to avoid them.

Learning Content of the Module:
▪ Data science methodologies ▪ Data quality ▪ Feature engineering ▪ Feature selection ▪ Building a predictive model ▪ Avoiding common fallacies

Teaching Methods:	See the contributing course outline
Literature:	See the contributing course outline

Percentage of the Module Grade Relative to the Final Grade for the Program:	**Prerequisites to Qualify for Assessment:**	**Assessment:**
5 ECTS of 60 ECTS = 8.33%	See course outline	<u>DLMDSME01:</u> Written Assessment: Case Study (100%)

<table>
<tr><td>Course No.:
DLMDSME01</td><td>Course Title:
Case Study: Model Engineering</td><td>Hours Total: 150

Credit Points: 5</td></tr>
<tr><td colspan="2">Course Type: Compulsory
Course Availability: In each semester
Course Duration: Minimum 1 semester</td><td>Admission Requirements:
Please see module description.</td></tr>
<tr><td colspan="2">Course Coordinator / Instructor:
See current list of tutors in the Learning Management System.</td><td>References to Other Modules:
Please see module description.</td></tr>
</table>

Course Description:

The construction of data science models and applying the techniques to real-world problems requires a deep understanding of data science processes and techniques beyond the application of relevant algorithms.

This course starts by introducing two commonly used data science methodologies: CRISP-DM and MS Team Data Science. Any data taken from real machines, systems, or processes will include some errors to varying degrees. This course discusses in detail how to detect and correct data quality issues, including the importance of domain knowledge in the determination of the veracity of the data.

Many machine learning approaches require the creation and subsequent selection of model features which determine which part of the data are used in which way in the later modelling step. This course discusses methods to engineer and build new features from raw data and outlines statistical methods to identify the most relevant features for the given task.

Finally, this course outlines strategies to avoid common fallacies when building data science models, as well as approaches to automate workflows.

Course Objectives and Outcome:

On successful completion of this course, students will be able to:

- understand current data science methodologies.
- devaluate the quality of the data used in data science projects.
- create new features from raw data.
- apply feature selection techniques.
- make predictive models using data science techniques.
- identify common fallacies and know how to avoid them.

Teaching Methods:

The learning materials include printed and online course books, vodcasts, online knowledge tests, podcasts, online tutorials, and case studies. This range of learning materials is offered to students so they can study at a time, place, and pace that best suits their circumstances and individual learning style.

Course Content:

1. **Data Science Methodologies**
   1.1. CRISP-DM
   1.2. MS Team Data Science
2. **Data Quality**
   2.1. Evaluating data quality
   2.2. Using low quality data
   2.3. Data duality and domain knowledge
3. **Feature Engineering**
   3.1. Building new features
   3.2. Splitting variables
   3.3. Feature engineering exploiting domain knowledge
4. **Feature Selection**
   4.1. Univariate feature selection
   4.2. Model based feature selection
5. **Building a Predictive Model**
   5.1. Establishing a benchmark model
   5.2. Prediction as probabilities
   5.3. Interpretable machine learning and results
6. **Avoiding Common Fallacies**
   6.1. Overtraining & generalization
   6.2. Overfitting & Occam's Razor
   6.3. Workflow automation and model persistence

Literature:

- Chapman, P. (n.d.). CRISP-DM user guide [PDF document]. Retrieved from https://s2.smu.edu/~mhd/8331f03/crisp.pdf
- Geron, A. (2017). *Hands-on machine learning with Scikit-Learn and TensorFlow.* Boston, MA: O'Reilly Publishing.
- Kuhn, M., & Johnson, K. (2013). *Applied predictive modeling.* New York, NY: Springer.
- Maydanchik, A. (2007). *Data quality assessment.* New Jersey: Technics Publications.
- Microsoft. (2017). Team Data Science Process Documentation. Retrieved from https://docs.microsoft.com/en-us/azure/machine-learning/team-data-science-process/overview
- Müller, A., & Guido, S. (2016). *Introduction to machine learning with Python: A guide for data scientists.* Boston, MA: O'Reilly.
- Olson, J. (2003). *Data quality – The accuracy dimension.* San Francisco, CA: Morgan Kaufmann.

A current list with course-specific compulsory reading, as well as references to further literature, is stored in the Learning Management System.

Prerequisites to Qualify for Assessment:	▪ Depending on the course: Completion of online knowledge tests (approx. 15 minutes per unit, pass / not pass)	x
Assessment:	▪ Written Assessment: Case Study	
Student Workload (in hours): 150	Self-study: 110 Self-testing: 20 Tutorials: 20	

Electives

Module DLMDSEBDSE

Big Data and Software Engineering

10 ECTS

Minimum duration of the module: **1 semester**

Admission requirements: Programming with Python (DLMDSPWP01)

Module Description

<table>
<tr><td>Module Title:</td><td colspan="2">Big Data and Software Engineering</td></tr>
<tr><td>Module No.:
DLMDSEBDSE</td><td>Semester / Term:
2nd semester</td><td>Duration:
Minimum 1 semester</td></tr>
<tr><td>Module Type(s):</td><td>Elective</td><td>Regularly Offered in:
WS / SS</td></tr>
<tr><td colspan="2">Workload: 300 h</td><td>Credit Points: 10</td></tr>
<tr><td colspan="2">Admission Requirements:
Programming with Python (DLMDSPWP01)</td><td>Language of Instruction:
English</td></tr>
<tr><td colspan="2">Contributing Courses to Module:
▪ Big Data Technologies (DLMDSBDT01)
▪ Software Engineering for Data Intensive Sciences (DLMDSSEDIS01)</td><td>Workload:
Self-study: 220h
Self-examination: 40 h
Tutorials: 40 h</td></tr>
<tr><td colspan="2">Course Coordinator(s) / Tutor(s):
Please see the current list of tutors on the Learning Management System.</td><td>Module Director:
N.N. Professur für Big Data Management</td></tr>
<tr><td colspan="2">References to Other Degree Programs:
▪ None</td><td>References to Other Modules in this Degree Program:
▪ Case Study: Model Engineering
▪ Machine Learning</td></tr>
</table>

Qualification and Educational Objectives of the Module:

Big Data Technologies (DLMDSBDT01)

On successful completion of this course in the module, students will be able to:

- identify the different types and sources of data.
- understand different database concepts.
- build new database structures.
- evaluate various data storage frameworks w.r.t. project requirements.
- analyze which data format to use for a given project.
- create a distributed computing environment for a given project.

Software Engineering for Data-Intensive Sciences (DLMDSSEDIS01)

On successful completion of this course in the module, students will be able to:

- understand the agile approaches Scrum and Kanban.
- explain how DevOps brings software development and operations together into one team.
- write high-quality code using relevant software development techniques.
- evaluate the requirements for APIs.
- create APIs for software applications.
- identify the challenges of bringing a model into production.

Learning Content of the Module:

Big Data Technologies (DLMDSBDT01)

- Data types and data sources
- Databases
- Modern storage frameworks
- Data formats
- Distributed computing

Software Engineering for Data-Intensive Sciences (DLMDSSEDIS01)

- Agile project management
- DevOps
- Software development
- API
- From model to production

Teaching Methods:	See the contributing course outline	
Literature:	See the contributing course outline	
Percentage of the Module Grade Relative to the Final Grade for the Program: 10 ECTS of 60 ECTS = 16.67%	**Prerequisites to Qualify for Assessment:** See course outline	**Assessment:** DLMDSBDT01: Oral Assignment (50%) DLMDSSEDIS01: Oral Assignment (50%)

Course No.: DLMDSBDT01	**Course Title:** Big Data Technologies	**Hours Total:** 150 **Credit Points:** 5
Course Type: Elective **Course Availability:** In each semester **Course Duration:** Minimum 1 semester		**Admission Requirements:** None
Course Coordinator / Instructor: See current list of tutors in the Learning Management System.		**References to Other Modules:** Please see module description.

Course Description:

Data are often considered the "new oil", the raw material from which value is created. To harness the power of data, the data need to be stored and processed on a technical level. This course introduces the four "Vs" of data, as well as typical data sources and types.

This course then discusses how data are stored in databases. Particular focus is given to database structures and different types of databases, e.g., relational, noSQL, NewSQL, and time-series.

Beyond classical and modern databases, this course covers a wide range of storage frameworks such as distributed filesystems, streaming, and query frameworks. This is complemented by a detailed discussion of data storage formats ranging from classical approaches such as CSV and HDF5 to more modern approaches like Apache Arrow and Parquet.

Finally, this course gives an overview of distributed computing environments based on local clusters, cloud computing facilities, and container-based approaches.

Course Objectives and Outcome:

On successful completion of this course, students will be able to:

- identify the different types and sources of data.
- understand different database concepts.
- build new database structures.
- evaluate various data storage frameworks w.r.t. project requirements.
- analyze which data format to use for a given project.
- create a distributed computing environment for a given project.

Teaching Methods:

The learning materials include printed and online course books, vodcasts, online knowledge tests, podcasts, online tutorials, and case studies. This range of learning materials is offered to students so they can study at a time, place, and pace that best suits their circumstances and individual learning style.

Course Content:

1. **Data Types and Data Sources**
   1.1. The 4Vs of data: volume, velocity, variety, veracity
   1.2. Data sources
   1.3. Data types
2. **Databases**
   2.1. Database structures
   2.2. Introduction to SQL
   2.3. Relational databases
   2.4. nonSQL, NewSQL databases
   2.5. Timeseries DB
3. **Modern data storage frameworks**
   3.1. Distributed Filesystems
   3.2. Streaming frameworks
   3.3. Query frameworks
4. **Data formats**
   4.1. Traditional data exchange formats
   4.2. Apache Arrow
   4.3. Apache Parquet
5. **Distributed Computing**
   5.1. Cluster-based approaches
   5.2. Containers
   5.3. Cloud-based approaches

Literature:

- Date, C. J. (2012). *Database design and relational theory: Normal forms and all that jazz*. Sebastopol, CA: O'Reilly Publishing.
- Karau, H., Konwinski, A., Wendell, A., & Zaharia, M. (2015). *Learning spark: Lightning-fast data analysis*. Sebastopol, CA: O'Reilly Publishing.
- Narkhede, N., Shapira, G., & Palino, T. (2017). *Kafka: The definitive guide: Real-time data and stream processing at scale*. Sebastopo, CA: O'Reilly Publishing.
- Poulton, N. (2017). *Docker deep dive*. Nigel Poulton.
- Psaltis, A. (2017). *Streaming data: Understanding the real-time pipeline*. Shelter Island, NY: Manning Publications.
- Redmond, E., & Wilson, J. R. (2012). *Seven databases in seven weeks: A guide to modern databases and the noSQL movement*. Dallas, TX: Pragmatic Bookshelf.
- Sadalage, P., & Fowler, M. (2012). *NoSQL distilled: A brief guide to the emerging world of polyglot persistence*. Ann Arbor, MI: Addison-Wesley.
- Viescas, J., & Hernandez, M. (2014). *SQL queries for mere mortals: A hands-on guide to data manipulation in SQL,* (3rd ed.). Ann Arbor, MI: Addison-Wesley.
- White, T. (2015). Hadoop: The definitive guide: Storage and analysis at Internet scale. Sebastopol, CA: O'Reilly Publishing.

A current list with course-specific compulsory reading, as well as references to further literature, is stored in the Learning Management System.

Prerequisites to Qualify for Assessment:	▪ Depending on the course: Completion of online knowledge tests (approx. 15 minutes per unit, pass / not pass)	x
Assessment:	▪ Oral Assignment	
Student Workload (in hours): 150	Self-study: 110 Self-testing: 20 Tutorials: 20	

<table>
<tr><td>Course No.:
DLMDSSEDIS01</td><td>Course Title:
Software Engineering for Data-Intensive Sciences</td><td>Hours Total: 150
Credit Points: 5</td></tr>
<tr><td colspan="2">Course Type: Elective
Course Availability: In each semester
Course Duration: Minimum 1 semester</td><td>Admission Requirements:
Please see module description.</td></tr>
<tr><td colspan="2">Course Coordinator / Instructor:
See current list of tutors in the Learning Management System.</td><td>References to Other Modules:
Please see module description.</td></tr>
</table>

Course Description:

Building a successful data-based product requires a significant amount of high-quality code which needs to run in a professional production environment. This course starts by introducing the agile approaches Scrum and Kanban and then discusses the shift from more traditional software development approaches to the DevOps culture.

Special focus is given to the discussion and understanding of techniques and approaches for producing high-quality code such as unit and integration testing, test-driven development, pair programing, and continuous delivery and integration.

Since many software artefacts are accessed via APIs, this course introduces concepts of API design and paradigms.

Finally, this course addresses the challenges of bringing code into a production environment, building a scalable environment, and using cloud-cased approaches.

Course Objectives and Outcome:

On successful completion of this course, students will be able to:

- understand the agile approaches Scrum and Kanban.
- explain how DevOps brings software development and operations together into one team.
- write high-quality code using relevant software development techniques.
- evaluate the requirements for APIs.
- create APIs for software applications.
- identify the challenges of bringing a model into production.

Teaching Methods:

The learning materials include printed and online course books, vodcasts, online knowledge tests, podcasts, online tutorials, and case studies. This range of learning materials is offered to students so they can study at a time, place, and pace that best suits their circumstances and individual learning style.

Course Content:

1. **Agile Project Management**
    1.1. Introduction to SCRUM
    1.2. Introduction to Kanban
2. **DevOps**
    2.1. Traditional lifecycle management
    2.2. Bringing development and operations together
    2.3. Impact of team structure
    2.4. Building a DevOps infrastructure
3. **Software Development**
    3.1. Unit & integration test, performance monitoring
    3.2. Test-driven development & pair programing
    3.3. Continuous delivery & integration
    3.4. Overview of relevant tools
4. **API**
    4.1. API design
    4.2. API paradigms
5. **From Model to Production**
    5.1. Building a scalable environment
    5.2. Model versioning and persistence
    5.3. Cloud-based approaches

Literature:

- Farcic, V. (2016). *The DevOps 2.0 toolkit: Automating the continuous deployment pipeline with containerized microservices*. Scotts Valley, CA: CreateSpace Independent Publishing Platform.
- Humble, J., & Farley, D. (2010). *Continuous delivery: Reliable software releases through build, test, and deployment automation*. Boston, MA: Addison-Wesley Professional.
- Humble, J., Molesky, J., & O'Reilly, B. (2015). *Lean enterprise*. Sebastopol, CA: O'Reilley Publishing.
- Hunt, A., & Thomas, D. (1999). *The pragmatic programmer. From journeyman to master.* Reading, MA: Addison-Wesley.
- Martin, R. C. (2008). *Clean code*. Boston, MA: Prentice Hall.
- Morris, K. (2016). *Infrastructure as code*. Sebastopol, CA: O'Reilley Publishing.
- Richardson, L., & Ruby, S. (2007). RESTful web services. Sebastopol, CA: O'Reilley Publishing.
- Senge, P. (1990). *The fifth discipline: The art and practice of the learning* organization. New York, NY: Broadway Business.

A current list with course-specific compulsory reading, as well as references to further literature, is stored in the Learning Management System.

Prerequisites to Qualify for Assessment:	▪ Depending on the course: Completion of online knowledge tests (approx. 15 minutes per unit, pass / not pass)	x
Assessment:	▪ Oral Assignment	
Student Workload (in hours): 150	Self-study: 110 Self-testing: 20 Tutorials: 20	

Module DLMDSESMMI

Smart Manufacturing Methods and Industrial Automation

10 ECTS

Minimum duration of the module: **1 semester**

Admission requirements: **None**

Module Description

<table>
<tr><td>Module Title:</td><td colspan="2">Smart Manufacturing Methods and Industrial Automation</td></tr>
<tr><td>Module No.:
DLMDSESMMI</td><td>Semester / Term:
2nd semester</td><td>Duration:
Minimum 1 semester</td></tr>
<tr><td>Module Type(s):</td><td>Elective</td><td>Regularly Offered in:
WS / SS</td></tr>
<tr><td colspan="2">Workload: 300 h</td><td>Credit Points: 10</td></tr>
<tr><td colspan="2">Admission Requirements:
None</td><td>Language of Instruction:
English</td></tr>
<tr><td colspan="2">Contributing Courses to Module:
▪ Manufacturing Methods Industry 4.0 (DLMBMMIIT02)
▪ Industrial Automation (DLMDSINDA01)</td><td>Workload:
Self-study: 180 h
Self-examination: 60 h
Tutorials: 60 h</td></tr>
<tr><td colspan="2">Course Coordinator(s) / Tutor(s):
Please see the current list of tutors on the Learning Management System.</td><td>Module Director:
N.N. Professur für Data Science/AI</td></tr>
<tr><td colspan="2">References to Other Degree Programs:
▪ None</td><td>References to Other Modules in this Degree Program:
▪ Big Data Software Engineering
▪ Machine Learning</td></tr>
</table>

Qualification and Educational Objectives of the Module:

Manufacturing Methods Industry 4.0 (DLMBMMIIT02):

On successful completion of this course in the module, students will be able to:

- distinguish and discuss a broad range of use cases for the internet of things (IoT).
- understand and reflect upon different perspectives on IoT.
- apply distinct techniques to engineer internet-of-things products.
- evaluate and identify appropriate IoT communication technology and standards according to given IoT product requirements.
- reflect on the respective theoretical foundation, evaluate different approaches, and apply appropriate approaches to practical questions and cases.

Industrial Automation (DLMDSINDA01):

On successful completion of this course in the module, students will be able to:

- identify the main issues related to industrial automation and Industry 4.0 automation in particular.
- describe a discrete event system in a formal way by means of different mathematical models.
- analyze the performance of a system using formalisms and numerical simulation approaches.
- choose the best formalism for a given design scenario and formulate requirements.
- design and implement a supervisory controller to fulfill requirements.
- understand advanced topics related to Industry 4.0 industrial automation.

Learning Content of the Module:

Manufacturing Methods Industry 4.0 (DLMBMMIIT02):

- Forming
- Cutting
- Rapid prototyping
- Rapid tooling
- Direct manufacturing

Industrial Automation (DLMDSINDA01):

- Mathematical frameworks for the formal description of discrete event systems
- Analysis and evaluation methods
- Simulation of discrete event systems
- Supervisory control
- Advanced issues (fault diagnosis, adaptive supervision, optimization)

Teaching Methods:	See the contributing course outline	
Literature:	See the contributing course outline	
Percentage of the Module Grade Relative to the Final Grade for the Program: 10 ECTS of 60 ECTS = 16.67%	**Prerequisites to Qualify for Assessment:** See course outline	**Assessment:** Module Exam 180 min (100%)

<table>
<tr><td>Course No.:
DLMBMMIIT02</td><td>Course Title:
Manufacturing Methods Industry 4.0</td><td>Hours Total: 150

Credit Points: 5</td></tr>
<tr><td colspan="2">Course Type: Elective
Course Availability: In each semester
Course Duration: Minimum 1 semester</td><td>Admission Requirements:
None</td></tr>
<tr><td colspan="2">Course Coordinator / Instructor:
See current list of tutors in the Learning Management System.</td><td>References to Other Modules:
Please see module description.</td></tr>
</table>

Course Description:

The aim of the course is to enable students to evaluate and identify appropriate manufacturing methods in the context of Industry 4.0. For that purpose, the course provides a comprehensive introduction of such processes based on traditional, standardized manufacturing techniques that have influenced and are still influencing production processes through technological developments under the generic term Industry 4.0. These include technological advances in additive manufacturing processes that enable applications such as rapid prototyping, rapid tooling, and direct manufacturing. Finally, the course deals with the consequences of the digitization and networking of production facilities and their elements in terms of a cyber-physical system.

Course Objectives and Outcome:

On successful completion of this course, students will be able to:

- evaluate different manufacturing methods against given product and process requirements.
- define and design modern additive techniques in contrast to traditional manufacturing.
- assess and estimate the impact of current trends on manufacturing like cyber-physical systems to given manufacturing challenges and practical problems.
- apply modern processes like rapid prototyping, rapid tooling, and direct manufacturing.

Teaching Methods:

The learning materials include printed and online course books, vodcasts, online knowledge tests, podcasts, online tutorials, and case studies. This range of learning materials is offered to students so they can study at a time, place, and pace that best suits their circumstances and individual learning style.

Course Content:

1. **Introduction to Manufacturing Methods**
    1.1. Basic Concepts
    1.2. Historical Development of Manufacturing
    1.3. About the Long Tail
2. **Manufacturing Methods**
    2.1. Casting and Molding
    2.2. Shaping
    2.3. Machining
    2.4. Joining
    2.5. Coating
3. **Additive Manufacturing and 3D printing**
    3.1. Basics and Legal Aspects
    3.2. Material Extrusion
    3.3. Vat Polymerization
    3.4. Powder Bed Fusion
    3.5. Material Jetting
    3.6. Binder Jetting
    3.7. Direct Energy Deposition
    3.8. Sheet Lamination
4. **Rapid Prototyping**
    4.1. Definitions
    4.2. Strategical and Operative Aspects
    4.3. Application Scenarios
5. **Rapid Tooling**
    5.1. Definitions
    5.2. Direct and Indirect Methods
    5.3. Application Scenarios
6. **Direct/Rapid Manufacturing**
    6.1. Potentials and Requirements
    6.2. Implementation Examples
7. **Cyber-Physical Production Systems**
    7.1. Introduction
    7.2. Cyber-Physical Production Systems
    7.3. Impact on Design and Maintenance of Plants
    7.4. Dynamic Reconfiguration of Plants
    7.5. Application Examples

Literature:

- Anderson, C. (2012). *Makers. The new industrial revolution*. New York, NY: Crown Business.
- Gad, S. (2008). *Implementing IT governance: A practical guide to global best practices in IT management*. Reading: Van Haren Publishing.
- Gebhardt, A. (2012). *Understanding additive manufacturing: Rapid prototyping – Rapid tooling – Rapid manufacturing*. München/Cincinnati, OH: Hanser.
- Groover, M. P. (2012). *Fundamentals of modern manufacturing: Materials, processes, and systems*. Hoboken, NJ: John Wiley & Sons Inc.

A current list with course-specific compulsory reading, as well as references to further literature, is stored in the Learning Management System.

Prerequisites to Qualify for Assessment:	▪ Depending on the course: Completion of online knowledge tests (approx. 15 minutes per unit, pass / not pass)	X
Assessment:	▪ Exam, 90 min.	
Student Workload (in hours): 150	Self-study: 90 Self-testing: 30 Tutorials: 30	

<table>
<tr><td rowspan="2">Course No.:
DLMDSINDA01</td><td rowspan="2">Course Title:
Industrial Automation</td><td>Hours Total: 150</td></tr>
<tr><td>Credit Points: 5</td></tr>
<tr><td colspan="2">Course Type: Elective
Course Availability: In each semester
Course Duration: Minimum 1 semester</td><td>Admission Requirements:
None</td></tr>
<tr><td colspan="2">Course Coordinator / Instructor:
See current list of tutors in the Learning Management System.</td><td>References to Other Modules:
Please see module description.</td></tr>
</table>

Course Description:

Production systems can be described as discrete event systems where the evolution is characterized by the occurrence of events. In the era of Industry 4.0 and highly-flexible manufacturing, there is the need to provide adequate means for the modeling, analysis, design, and control of flexible production environments.

This course introduces several modeling approaches for the mathematical description of discrete event systems, such as Automata, Petri Nets, and Markov processes. Each approach is presented in both theory and practice with examples taken from the industry. The approaches are grouped into logic—where only the logic sequence of events determines the evolution—and timed, where the time schedule of the events also plays an important role. Although simple discrete event systems can be analyzed mathematically, complex systems need the support of computer simulation. The main issues concerning the simulation of discrete event systems are addressed.

The final part of this course introduces the concept of supervisory control, which aims at changing the properties of a given system to improve specified behaviors and fulfill defined design specifications. Supervisory control is addressed both from the theoretical practical sides, describing how it can be implemented in a modern industrial environment.

The course wraps up with discussion of interesting applications for modeling and design approaches, e.g., in the modeling and analysis of an industrial production unit. Additional conversation on topics like fault-diagnosis, decentralized and distributed supervision, optimization, and adaptive supervision provide a contingent connection between classical industrial automation and the recent, (big) data-driven, flexible, Industry 4.0 advanced industrial automation.

Course Objectives and Outcome:

On successful completion of this course, students will be able to:

- identify the main issues related to industrial automation and Industry 4.0 automation in particular.
- describe a discrete event system in a formal way by means of different mathematical models.
- analyze the performance of a system using formalisms and numerical simulation approaches.
- choose the best formalism for a given design scenario and formulate requirements.
- design and implement a supervisory controller to fulfill requirements.
- understand advanced topics related to Industry 4.0 industrial automation.

Teaching Methods:

The learning materials include printed and online course books, vodcasts, online knowledge tests, podcasts, online tutorials, and case studies. This range of learning materials is offered to students so they can study at a time, place, and pace that best suits their circumstances and individual learning style.

Course Content:

1. **Introduction to Production Systems**
   1.1. Basic concepts and definitions
   1.2. Industrial supervision and control
   1.3. Challenges
   1.4. Trends
2. **Automata**
   2.1. Preliminaries
   2.2. Deterministic finite automata
   2.3. Non-deterministic finite automata
   2.4. Properties
3. **Petri nets**
   3.1. Preliminaries
   3.2. Modeling systems
   3.3. Properties
   3.4. Analysis methods
4. **Timed models**
   4.1. Timed automata
   4.2. Markov processes
   4.3. Queuing theory
   4.4. Timed Petri Nets
5. **Simulation of discrete event systems**
   5.1. Basic concepts
   5.2. Working principles
   5.3. Performance analysis
   5.4. Software tools
6. **Supervisory control**
   6.1. Basic concepts
   6.2. Specifications
   6.3. Synthesis
   6.4. Performance analysis
   6.5. Implementation
7. **Applications**
   7.1. Production system supervision
   7.2. Monitoring and diagnosis of faults
   7.3. Distributed and de-centralized supervision
   7.4. Model-based optimization of production systems
   7.5. Adaptive supervisory control

Literature:

- Cassandras, C. G., & Lafortune, S. (Eds.). (2008). *Introduction to discrete event systems*. Boston, MA: Springer US.
- Seatzu, C., Silva, M., & van Schuppen, J. H. (Eds.). (2013). *Control of discrete-event systems*. London: Springer London.
- Ding, D., Wang, Z., & Wei, G. (2018). *Performance analysis and synthesis for discrete-time stochastic systems with network-enhanced complexities*. Boca Raton, FL: CRC Press.
- Zimmermann, A. (2008). *Stochastic discrete event systems*. Berlin, Heidelberg: Springer Berlin Heidelberg.
- Hrúz, B., & MengChu, Z. (2007). *Modeling and control of discrete-event dynamic systems*. London: Springer London.
- Choi, B. K., & Kang, D. (2013). *Modeling and simulation of discrete-event systems*. Hoboken, NJ: Wiley.
- Wonham, W. M., & Cai, K. (2019). *Supervisory control of discrete-event systems*. Cham: Springer International Publishing.

A current list with course-specific compulsory reading, as well as references to further literature, is stored in the Learning Management System.

Prerequisites to Qualify for Assessment:	▪ Depending on the course: Completion of online knowledge tests (approx. 15 minutes per unit, pass / not pass)	x
Assessment:	▪ Exam, 90 min.	
Student Workload (in hours): 150	Self-study: 90 Self-testing: 30 Tutorials: 30	

Applied Autonomous Driving

10 ECTS

Minimum duration of the module: **1 semester**

Admission requirements: **None**

Module Description

<table>
<tr><td>Module Title:</td><td colspan="2">Applied Autonomous Driving</td></tr>
<tr><td>Module No.:
DLMDSEAAD</td><td>Semester / Term:
2nd semester</td><td>Duration:
Minimum 1 semester</td></tr>
<tr><td>Module Type(s):</td><td>Elective</td><td>Regularly Offered in:
WS / SS</td></tr>
<tr><td colspan="2">Workload: 300 h</td><td>Credit Points: 10</td></tr>
<tr><td colspan="2">Admission Requirements:
None</td><td>Language of Instruction:
English</td></tr>
<tr><td colspan="2">Contributing Courses to Module:
▪ Architectures of Self-Driving Vehicles (DLMDSEAAD01)
▪ Case Study: Localization, Motion Planning, and Sensor Fusion (DLMDSEAAD02)</td><td>Workload:
Self-study: 200 h
Self-examination: 50 h
Tutorials: 50 h</td></tr>
<tr><td colspan="2">Course Coordinator(s) / Tutor(s):
Please see the current list of tutors on the Learning Management System.</td><td>Module Director:
N.N. Professur für Artificial Intelligence</td></tr>
<tr><td colspan="2">References to Other Degree Programs:
▪ Master in Artificial Intelligence (120 ECTS)</td><td>References to Other Modules in this Degree Program:
▪ Machine Learning</td></tr>
</table>

Qualification and Educational Objectives of the Module:

Architectures of Self-Driving Vehicles (DLMDSEAAD01)

On successful completion of this course in the module, students will be able to:

- explain and recognize the main components of a self-driving car.
- distinguish the sensor solutions for a self-driving car and adopt the best one for a given scenario.
- model and implement a simple motion control system.
- manage the main communication protocols to retrieve valuable information.
- reflect on the social impact of self-driving cars.

Case Study: Localization, Motion Planning, and Sensor Fusion (DLMDSEAAD02)

On successful completion of this course in the module, students will be able to:

- distinguish the methods used for localization, motion planning, and sensor fusion.
- apply the methods to autonomous vehicles.
- understand the main issues related to the adoption of autonomous vehicles in real-world scenarios.

Learning Content of the Module:

Architectures of Self-Driving Vehicles (DLMDSEAAD01):

- Architectural patterns of a self-driving car
- Perception and motion control
- Social impact of autonomous vehicles

Case Study: Localization, Motion Planning, and Sensor Fusion (DLMDSEAAD02):

- Algorithms for localization and navigation
- Sensor fusion methods for localization and objects tracking
- Motion planning algorithms

Teaching Methods:	See the contributing course outline
Literature:	See the contributing course outline

Percentage of the Module Grade Relative to the Final Grade for the Program:	**Prerequisites to Qualify for Assessment:**	**Assessment:**
10 ECTS of 60 ECTS = 16.67%	See course outline	DLMDSEAAD01: Exam, 90 min. (50%) DLMDSEAAD02: Written Assessment: Case Study (50%)

<table>
<tr><td>Course No.:
DLMDSEAAD01</td><td>Course Title:
Architectures of Self-Driving Vehicles</td><td>Hours Total: 150
Credit Points: 5</td></tr>
<tr><td colspan="2">Course Type: Elective
Course Availability: In each semester
Course Duration: Minimum 1 semester</td><td>Admission Requirements:
None</td></tr>
<tr><td colspan="2">Course Coordinator / Instructor:
See current list of tutors in the Learning Management System.</td><td>References to Other Modules:
Please see module description.</td></tr>
</table>

Course Description:

This course gives an overview of the main architectural aspects of a self-driving car. After introducing the hardware and software platforms, the course presents the sensor solutions necessary to provide environment perception for autonomous vehicles. Such perception yields the information used for motion control, including braking and steering. The fundamental concepts for the realization and implementation of motion control are presented, together with related safety issues (e.g., motion control under false information). The way in which a self-driving car exchanges information with the outside world is also discussed, and the main technologies and protocols are introduced. The last part of the course elaborates on the social impact of self-driving cars: ethics, mobility, and design.

Course Objectives and Outcome:

On successful completion of this course, students will be able to:

- explain and recognize the main components of a self-driving car.
- distinguish the sensor solutions for a self-driving car and adopt the best one for a given scenario.
- model and implement a simple motion control system.
- manage the main communication protocols to retrieve valuable information.
- reflect on the social impact of self-driving cars.

Teaching Methods:

The learning materials include printed and online course books, vodcasts, online knowledge tests, podcasts, online tutorials, and case studies. This range of learning materials is offered to students so they can study at a time, place, and pace that best suits their circumstances and individual learning style.

Course Content:

1. **Introduction**
   1.1. Basic concepts and key technologies
   1.2. Hardware overview
   1.3. Software overview
   1.4. State of the art and open challenges
   1.5. Trends
2. **Environment Perception**
   2.1. Basic concepts
   2.2. GPS
   2.3. Inertial sensors
   2.4. Lidar and Radar
   2.5. Cameras
3. **Moving, Braking, Steering**
   3.1. Fundamentals
   3.2. Dynamics of a mobile vehicle
   3.3. Braking technologies
   3.4. Lateral and longitudinal control
   3.5. Safety issues
4. **Communication**
   4.1. Car2X communication
   4.2. Protocols
   4.3. Safety issues
5. **Social Impact**
   5.1. Ethics for autonomous vehicles
   5.2. New mobility
   5.3. Autonomous vehicles and design

Literature:

- Ben-Ari, M., & Mondada, F. (2018). *Elements of robotics*. Cham: Springer.
- Cheng, H. (2011). *Autonomous intelligent vehicles*. London: Springer.
- Fazlollahtabar, H., & Saidi-Mehrabad, M. (2015). *Autonomous guided vehicles*. Cham: Springer.
- Maurer, M., Gerdes, J. C., Lenz, B., & Winner, H. (Eds.). (2016). *Autonomous driving*. Berlin, Heidelberg: Springer.
- Miucic, R. (Ed.). (2019). *Connected vehicles*. Cham: Springer.
- Yu, H., Li, X., Murray, R. M., Ramesh, S., & Tomlin, C. J. (Eds.). (2019). *Safe, autonomous and intelligent vehicles*. Cham: Springer.

A current list with course-specific compulsory reading, as well as references to further literature, is stored in the Learning Management System.

Prerequisites to Qualify for Assessment:	▪ Depending on the course: Completion of online knowledge tests (approx. 15 minutes per unit, pass / not pass)	x
Assessment:	▪ Exam, 90 min.	
Student Workload (in hours): 150	Self-study: 90 Self-testing: 30 Tutorials: 30	

Course No.: DLMDSEAAD02	Course Title: Case Study: Localization, Motion Planning, and Sensor Fusion	Hours Total: 150 Credit Points: 5
Course Type: Elective **Course Availability:** In each semester **Course Duration:** Minimum 1 semester		**Admission Requirements:** None
Course Coordinator / Instructor: See current list of tutors in the Learning Management System.		**References to Other Modules:** Please see module description.

Course Description:

This course provides the fundamental concepts and methods of localization, motion planning, and sensor fusion for mobile robotics and self-driving cars. Mobile robots and autonomous vehicles rely on the ability to perceive the environment and react to its dynamic changes.

The first part of the course focuses on the representation of motion and navigation based on odometry, which is affected by errors due to information uncertainty. A possible solution is offered by localization methods which use odometry and complementary information, such as a GPS signal, to improve the estimation of the position of the autonomous vehicles within a reference frame. In this way, the vehicle is able to move towards a goal.

The problems with detecting dynamic change in the environment is addressed in the last part of the course, where the methods of sensor fusion are introduced. Thanks to the fusion of multiple data sources, information can be extracted, e.g., an approaching object or a change in a situation can be revealed. The autonomous vehicle must be able to track the object and react to its movement to avoid human hazard and damage. The determination of the best trajectory to follow is addressed in the final part of the course.

The course gives a hands-on overview of the main methods for localization, motion planning, and sensor fusion. The students must apply the concepts and methods to case studies involving a self-driving vehicle in two main scenarios: “on the road” and in a manufacturing facility.

Course Objectives and Outcome:

On successful completion of this course, students will be able to:

- distinguish the methods used for localization, motion planning, and sensor fusion.
- apply the methods to autonomous vehicles.
- understand the main issues related to the adoption of autonomous vehicles in real-world scenarios.

Teaching Methods:

The learning materials include printed and online course books, vodcasts, online knowledge tests, podcasts, online tutorials, and case studies. This range of learning materials is offered to students so they can study at a time, place, and pace that best suits their circumstances and individual learning style.

Course Content:

1. **Motion and Odometry**
   1.1. Basic principles
   1.2. Motion models
   1.3. Navigation by odometry
   1.4. Holonomic and non-holonomic motion
   1.5. Errors
2. **Local Navigation**
   2.1. Basic concepts
   2.2. Path finding
   2.3. Obstacle avoidance
3. **Localization**
   3.1. Basic concepts
   3.2. Triangulation
   3.3. GPS
   3.4. Probabilistic localization
   3.5. Uncertainty of motion
4. **Sensor Fusion**
   4.1. Sensors
   4.2. Elaborating data from sensors
   4.3. Kalman filter
   4.4. Extended Kalman filter
   4.5. Tracking objects
5. **Motion Planning**
   5.1. Path planning
   5.2. Motion prediction
   5.3. Trajectory generation

Literature:

- Koch, W., & Springer-Verlag GmbH. (n.d.). *Tracking and sensor data fusion methodological framework and selected applications*. Berlin, Heidelberg: Springer.
- Marchthaler, R., & Dingler, S. (2017). *Kalman-Filter*. Wiesbaden: Springer.
- Mitchell, H. B. (2007). *Multi-sensor data fusion: An introduction*. Berlin, Heidelberg: Springer.
- Valencia, R., & Andrade-Cetto, J. (2018). *Mapping, planning and exploration with Pose SLAM*. Cham: Springer.
- Wang, P. K.-C. (2015). *Visibility-based optimal path and motion planning*. Cham: Springer.

A current list with course-specific compulsory reading, as well as references to further literature, is stored in the Learning Management System.

Prerequisites to Qualify for Assessment:	▪ Depending on the course: Completion of online knowledge tests (approx. 15 minutes per unit, pass / not pass)	x
Assessment:	▪ Written Assessment: Case Study	
Student Workload (in hours): 150	Self-study: 110 Self-testing: 20 Tutorials: 20	

Module DLMMTHE

Master Thesis

20 ECTS

Minimum length of the module:	**1 semester**
Admission requirements:	**See study and exam regulation (SPO)**

Module Description

<table>
<tr><td>Module Title:</td><td colspan="2">Master Thesis</td></tr>
<tr><td>Module No.:
DLMMTHE</td><td>Semester / Term:
2nd semester</td><td>Duration:
1 Semester</td></tr>
<tr><td>Module Type(s):</td><td>Compulsory</td><td>Regularly Offered In:
WS / SS</td></tr>
<tr><td colspan="2">Workload: 600 h</td><td>Credits: 20</td></tr>
<tr><td colspan="2">Admission Requirements:
See current study and exam regulations (SPO)</td><td>Language of Instruction:
English</td></tr>
<tr><td colspan="2">Contributing Courses to Module:
▪ Master Thesis (DLMMETHE01)
▪ Thesis Defense (DLMMETHE02)</td><td>Workload:
Research & Writing: 540 h
Thesis Defense: 60 h</td></tr>
<tr><td colspan="2">Course Coordinator(s) / Tutor(s):
See the current list of tutors on the Learning Management System.</td><td>Module Director:
Prof. Dr. Holger Sommerfeldt</td></tr>
<tr><td colspan="2">References to Other Programs:
▪ none</td><td>References to Other Modules in the Program:
▪ All modules in the master program</td></tr>
<tr><td colspan="3">Qualification and Educational Objectives of the Module:

The module master thesis includes the courses Master Thesis and Thesis Defense. The master thesis is an extensive, scholarly, written composition, where the student seeks to independently examine a topic using scientific methods, and where the arguments, results, and processes are documented.

The thesis defense will take place when the finished thesis has been handed in to the supervisor. The defense consists of a presentation detailing the outcomes of the thesis, and a question-and-answer session led by the examiners.</td></tr>
</table>

Learning Content of the Module: ▪ Written Master Thesis ▪ Thesis Defense		
Teaching Methods:	See the course description	
Literature:	See the reading list in the course description	
Percentage of the Module Grade of the Total Final Grade of the Program: 20 ECTS of 60 ECTS = 33.3 %	**Prerequisites to Qualify for Assessments:** See current study and exam regulations (SPO)	**Assessment:** ▪ DLMMETHE01: Master Thesis (90 %) (approx. 60 A4 pages) ▪ DLMMETHE02: Thesis Defense (10 %) (45 minutes)

Course No.: DLMMTHE01	**Course Title:** Master Thesis	**Total Hours:** 540 **Credits:** 18
Course Type: Compulsory **Course Availability:** in each semester **Course Duration:** 1 Semester		**Admission Requirements:** See current study and exam regulations (SPO)
Course Coordinator / Instructor: See current list of tutors on the Learning Management System.		**References to Other Modules:** All modules in the master program
Course Description: The aim of the master thesis is to effectively apply the knowledge acquired throughout the master course to an academic paper that has a thematic reference to the master program. The thesis can consist of an empirical study or theoretical research. The thesis is an independent piece of work, that, with the guidance of a supervisor, seeks to scientifically analyze and critically discuss a chosen issue, and suggest possible solutions. The chosen topic from the student's area of specialization should demonstrate their acquired competence in the functional area, yet also enrich and round out the student's scientific knowledge. This will optimally prepare the student for the needs of their future career path.		
Course Objectives and Outcome: The objective of this module is the completion of a written assignment, in line with scientific methodology, that demonstrates the student's capabilities through independent investigation of a topic pertaining to the master program's area of focus.		
Teaching Methods: While the students complete the thesis individually, guidance and feedback is provided through an academic supervisor.		

Course Content:

The master thesis should clearly state the topic and research question, and should, through extensive research, reflect the current state of the field in question. The student should demonstrate their knowledge in the form of an independent and solution oriented paper, using theoretical and/or empirical norms.

Recommended Literature:

- Bui, Y. N. (2013). *How to Write a Master's Thesis* (2nd ed.). SAGE Publications, Incorporated.
- Turabian, K. L. (2013). *A Manual for Writers of Research Papers, theses, and dissertations* (8th ed.). University of Chicago Press.
- Further subject specific literature

An actual list with course-specific mandatory reading as well as references to further literature is available in the Learning Management System.

Assessment:	Written assessment: Master Thesis (approx. 60 A4 pages) Two internal examiners will grade the thesis on the basis of an established grading rubric. The grading criteria are as follows: ▪ Extent, structure and objective of the research question ▪ Structure and development of research ▪ Analysis of key sources and choice of theoretical framework ▪ Rationale, presentation and use of the scientific approach and chosen methodology ▪ Presentation, interpretation and discussion of the theoretical and/or empirical findings ▪ Originality, creativity and independence of the academic writing ▪ Citation and use of sources ▪ Adherence to academic writing standards (citations, list of references, list of figures and tables etc.)
Student Workload (in hours): 540	Research / Academic Writing: 540 h

Course No.: DLMMTHE02	Course Title: Thesis Defense	Total Hours: 60 Credits: 2
Course Type: Compulsory **Course Availability:** in each semester **Course Duration:** 1 Semester		**Admission Requirements:** See current study and exam regulations (SPO)
Course Coordinator / Instructor: See current list of tutors on the Learning Management System.		**References to Other Modules:** All modules in the master program

Course Description:

The thesis defense takes place after the written master thesis has been handed in by the student. The examiners (the supervisor and a second examiner) will invite the student to the defense. During the presentation, the student will demonstrate that he/she personally has independently produced the content and the results of their written thesis.

The thesis defense consists of a presentation where the student discusses the most significant research outcomes and the results of their thesis, followed by a question-and-answer session chaired by the examiners.

Course Objectives and Outcome:

The main objective of the thesis defense is for the student to prove their competence in research methodology and the specific subject matter. The students should also be able to actively participate in a subject specific discussion at a higher academic level with subject area experts. Additionally, the defense will evaluate the academic presentation skills and overall communication skills of the student.

Teaching Methods:

The students will be provided with adequate presentation technologies.

Course Content:

The thesis defense consists of a presentation of the results and applied method of the master thesis, followed by a question-and-answer session chaired by the examiners.

Recommended Literature:

- Subject specific literature chosen by the student

Assessment:	▪ Presentation (15 minutes) ▪ Oral examination (30 minutes) The examiners evaluate the student according to the following grading criteria: ▪ Understanding and application of appropriate scientific methods ▪ Structure and content of the presentation ▪ Capability to academically defend a master thesis ▪ Quality of answers to the examination questions
Student Workload (in hours): 60 h	Preparation: 59 h Oral Exam: 1 h