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Master of Cyber Physical Systems

International Master of Science on Cyber Physical Systems

WP2: Development

D2.3 Master curricula courses report

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Contact Person	Christian Weber	**Organisation**	USI
Phone	+49 271 740 5199	**E-Mail**	christian.weber@uni-siegen.de
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Contributors

Name	Organization
This deliverable saw contributions from a wide range of contributors. However, only a selected few added their name to the list.	

Disclaimer

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1 Introduction

1.1 Abstract

This document captures the core of the study program: the modules, the composing learning outcomes, and courses, as well as the study programme concept. To do so concepts are introduced to create a mapping between the learning objective driven perspective of formal education and the more non-formal skills and competencies perspective of the markets. As an extension of this, D2.3 defines a MS@CPS framework for composing and implementing the master studies on a local level but also to introduce MS@CPS as a type of branding, rapidly transforming local study programs to CPS studies.

1.2 The purpose of this document

- This document describes a Framework for the master studies but is also acting as a guide to implement new MS@CPS study programs in the future.
- This includes an adaptation concept to apply the MS@CPS curriculum at local levels.

1.3 Relation to other deliverables

- D1.3 – the framework presented here is based on the courses, identified in D1.3.
- D2.1 – the construction of the framework is informed by the pedagogy which was drafted for an inclusive, sustainable, and transferable study programme concept.

1.4 Relation to work packages

WP1 collects the requirements of the overall curriculum building frame and delivers an input to the curriculum in terms of focused learning outcomes (LO) that can have a relationship to the application driven pedagogy parts. WP3 similarly collects and facilitates industrial requirements to the later study programme and enables to fine-tune the practical pedagogy in a way to accommodate a range of specific industrial curricula integrations under one homogeneous concept.

2 From Cyber-physical Systems Skills and Competencies to Learning Objectives

Cyber-physical systems (CPS) as a direction of thought and a discipline to master for high technology products and concepts, has been described now in several deliverables. See here especially D2.1. However, what continuous to make it unique and what informs this deliverable, is that CPS is a concept at the intersection of mechanical, electrical and software engineering, which not only motivates this intersection but needs the intersection to master the complexity of modern CPS systems. This comes with a catch. While each discipline is existing for multiple generations, they are not compatible on a level that is needed to truly master CPS systems. Assumptions, taken to simplify the model of the world to a manageable construct, do work well within the single disciplines but they do clash when combined to one fused implementation within the domain intersection.

So rather than being a fundamentally new discipline, CPS puts forth the challenge to develop new concepts for interlinking the existing disciplines to find new answers for problems of high complexity. This in turn means that a study programme for CPS is not about creating new courses but to combine courses in a way that in their intersection new answers are given on how to interlink disciplines and models alike to create new, complex systems but also to teach the fusion in new creative, cross-discipline manners.

MS@CPS answers the challenge by proposing a unique composition of courses, together with a practical, cross-domain vision for shared practical spaces (see D2.1). But MS@CPS also comes with the profit that the foundation that is needed to implement this study programme is available at most of the universities. Only the composition and the unique teaching concepts have to be adopted. Therefore, this document showcases the unique composition of courses, coming from a learning outcome perspective (see the collection of module descriptions in D2.2) and transitioning into a skill and competency perspective. This, mixed with the concepts of the MS@CPS pedagogy, enables to see MS@CPS as an overarching concept and a type of educational “brand” that enables a rapid transfer to, basically franchising the idea as a concept and label to create new local university programs that are unique in their CPS implementation but aligned to the MS@CPS framework.

However, it has to be highlighted that an adoption of existing courses is the base for creating a CPS master study program, but it has to go beyond adoption. It needs a six-fold adoption and sustainability cycle to ensure the domain intersection needed to teach CPS master studies:

1. Collect courses that reflect the target learning outcomes.
2. Investigate the state-of-solutions and the state-of-the-art to ensure the transferability of concepts on a complexity level of up-to-date CPS research and market solutions.
3. Use the identified concepts of the single courses and discuss overlaps and communalities that are needed to create a CPS perspective and skill set.
4. Apply the MS@CPS pedagogy to create and reflect practical formats that enable a cross-domain application of taught learning outcomes.
5. Evaluate the learning outcomes with learning assessment and qualitative surveys and analysis.
6. Repeat.

2.1 ESCO Skills and Competencies Framework

Before we look deeper into the MS@CPS framework, we will define the use of skills and competencies within this document. Training takes place in multiple environments, may it be formal, in terms of formal or formalized education, taught at certified institutions like universities, which then “certify” mastering of a study program, or, non-formal learning, with more open training concepts, teaching and training sets of skills in a semi- or fully non-formal environment, or informal learning, or called on-the-job-learning, where learning happens self-motivated while interacting with new situations, often not even being aware of the process of learning.

This leads to multiple institutions, organizations – public or private – do fertilize a market with a multitude of stakeholders and supporting disciplines. As such, the terms of skills, competencies and learning outcomes or objectives can easily mix in meaning, avoiding a unique, yet general definition that is accepted by all stakeholders. Therefore, we had to make a selection of a definition from the corpus of definitions in the literature and markets. The definition selected here is derived from the European ESCO initiative for a common, European understanding of skills and competencies and their match to jobs. From a formal-learning perspective the highest abstraction level is learning objectives, expressing the higher-level goals of learning in an abstract but transferable fashion, while each learning outcome may include one or multiple skills and competencies.

The ESCO definitions are cited in the following and will be used within this document in this specific vision:

- Skill: https://ec.europa.eu/esco/portal/escopedia/Skill

Skill

ESCO applies the same definition of "skill" as the European Qualifications Framework (EQF). According to this "skill means the ability to apply knowledge and use know-how to complete tasks and solve problems". They can be described as cognitive (involving the use of logical, intuitive and creative thinking) or practical (involving manual dexterity and the use of methods, materials, tools and instruments).

While sometimes used as synonyms, the terms skill and competence can be distinguished according to their scope. The term skill refers typically to the use of methods or instruments in a particular setting and in relation to defined tasks. The term competence is broader and refers typically to the ability of a person - facing new situations and unforeseen challenges - to use and apply knowledge and skills in an independent and self-directed way.

> *Example:*
>
> *Working as a "civil airline pilot" requires the competence to combine knowledge on "emergency procedures" and "equipment malfunctions" with skills on "reading position coordinates" and "following the air route". This application of knowledge and skills takes place in a partly unpredictable setting where technical and organisational problems occur on a daily basis and where solutions have to be immediately identified and applied – either by the pilot alone or through team-working (e.g. involving the cabin crew or the ground staff).*

In ESCO, skills are part of the skills pillar.

- Competence: https://ec.europa.eu/esco/portal/escopedia/Competence

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ESCO applies the same definition of "competence" as the European Qualification Framework (EQF). According to this "competence means the proven ability to use knowledge, skills and personal, social and/or methodological abilities, in work or study situations and in professional and personal development." They are described in terms of responsibility and autonomy.

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In ESCO, competences are part of the skills pillar.

2.2 Learning Objectives and the Education/Job Market Gap.

There is an ongoing gap between education and the fast-developing market. As such learning objectives can be seen also as a general level design element, utilized to address a larger field of skills and competencies, without changing as rapidly as the markets. This is based in the abstraction level of the learning objectives. To bridge the gap, section 4 in this document presents a mapping between the main skills and competencies of each study module and the defined, selected main learning outcomes of the composing courses.

2.3 Blooms Revised Taxonomy to Design Learning Objectives

To complete a successful mapping of skills, competencies and learning outcomes, the learning outcomes have to be considered and rated with more detail. The fundamental idea of learning outcomes is to offer an abstraction level that goes beyond the competences definition we have seen above. The less abstract a learning outcome is, the closer it is to being a competency or skill. However, the level of abstraction is usually hard to judge and evaluate. One tool to do so is Bloom's (revised) taxonomy.

Bloom's taxonomy is based on the idea that the outcomes of teaching can be sketched along a multi-level pyramid, as shown below in Figure 1. The concept is that learning can be seen as climbing, or mastering the pyramid, starting with remembering, converging to understanding, to then gain the ability to apply the learned till learning is wholesome enough to activate higher cognitive and creative functions that finally enable to create new artifacts based on the learned and also beyond the learned. A class can then be seen as a learning "climb" of mastering the taxonomy levels, while the instructor can decide till which level the education and therefore the learning outcomes should reach.

To make this easier, Bloom's taxonomy collects verbs that are typical for the implementation of the given level of mastering. I.e., "compose" is signalling an activity that needs a master level that fits to the "create" level of the taxonomy. Now this can be used to further evaluate learning outcomes, skills and competencies together, to see in what way the phrasing of the specific concept aligns to the levels of the pyramid, providing an indication for the fit of those concepts. I.e., if a skill includes the signal word "create" in the context of applied creativity, then it can be assumed that a given learning outcome in the same domain and with the same focus, will also require a similarly "high" level of mastering.

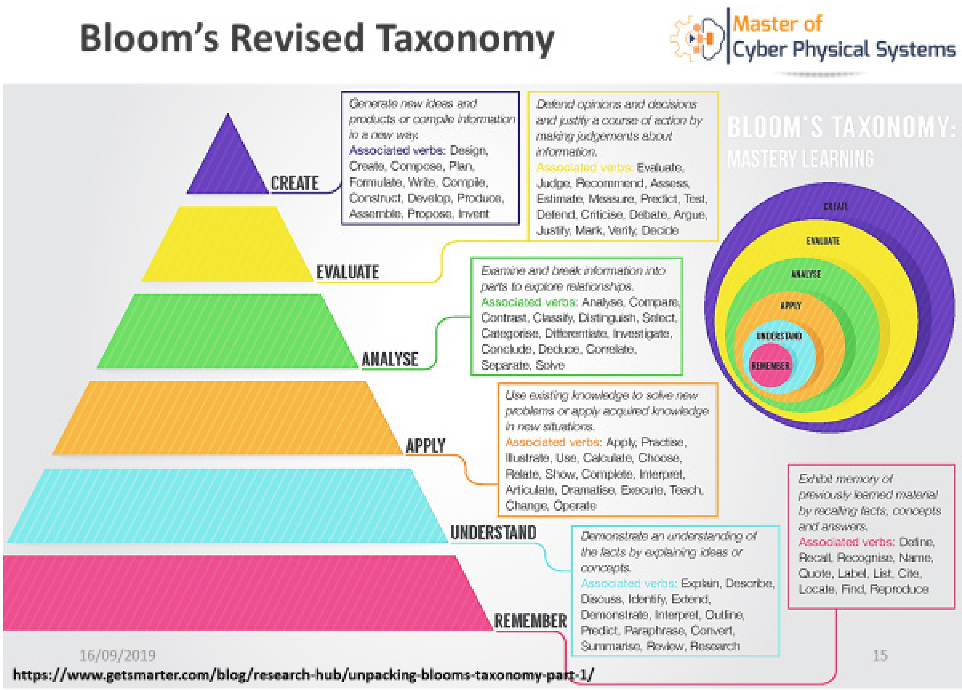
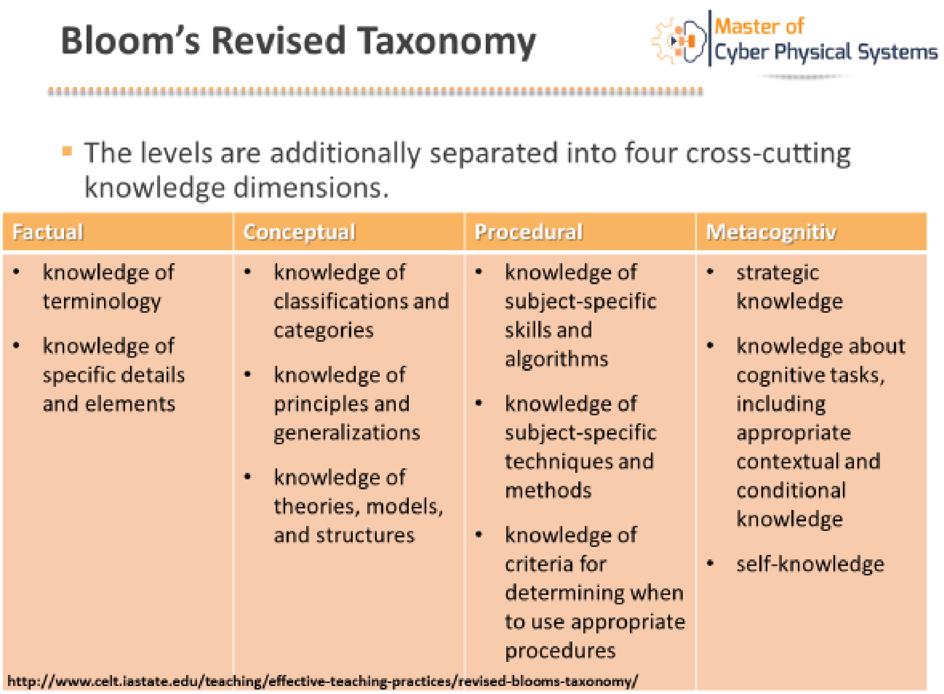


Figure 1: A visualization of Bloom's revised taxonomy, including a limited list of corresponding verbs.

Additionally, the taxonomy defines cross-cutting dimensions that can support to better classify a given part of a lecture and its learning outcomes for a more distinguished, detailed perspective. The categories are shown in Figure 2.



Factual	Conceptual	Procedural	Metacognitiv
• knowledge of terminology • knowledge of specific details and elements	• knowledge of classifications and categories • knowledge of principles and generalizations • knowledge of theories, models, and structures	• knowledge of subject-specific skills and algorithms • knowledge of subject-specific techniques and methods • knowledge of criteria for determining when to use appropriate procedures	• strategic knowledge • knowledge about cognitive tasks, including appropriate contextual and conditional knowledge • self-knowledge

Figure 2: Cross-cutting dimensions of the taxonomy.

This enables to see a given class and its objectives in a matrix of its mastering levels and dimensions, to gain a differentiated overview and evaluation of the composing parts of the class, as seen in Figure 3. This furthermore enables a distinct mapping to skills and competencies, considering those also through the matrix approach. The mapping is shown within section 4 of this deliverable for the core learning outcomes of each module. The specific match is always also informed by local factors, such as the teacher profile, learner profile, the study context and the composition of the practical support of courses as a course environment and finally also by socio-cultural factors. As such the core lists of skills and competencies are intended as a starting point for further defining skills and competencies on a local level.

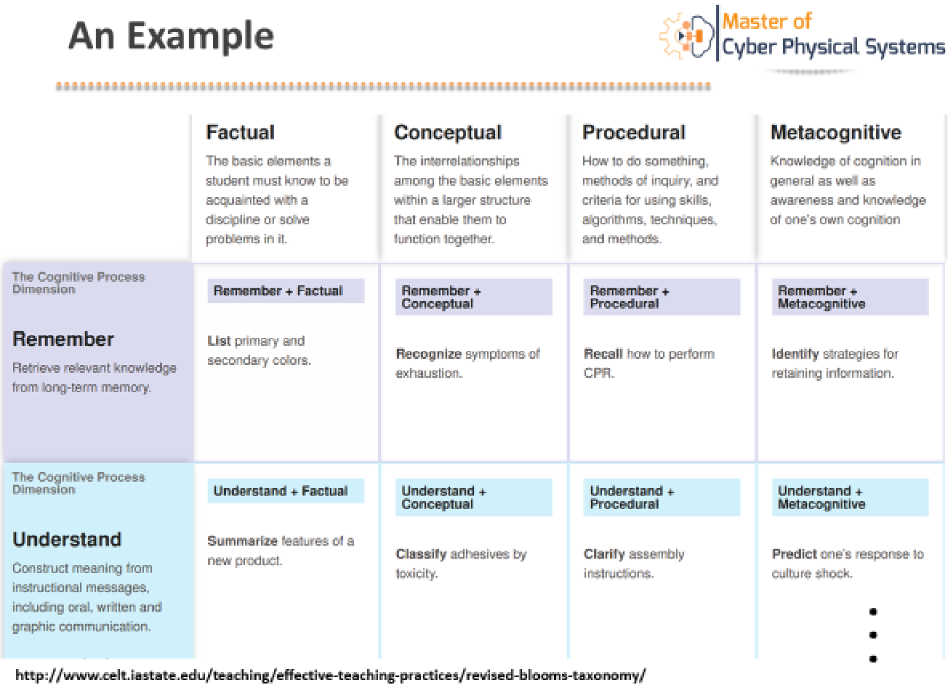


Figure 3: An example for a taxonomy matrix, combining mastery levels and their dimensions.

3 MS@CPS an International CPS Curriculum Framework

The input for the MS@CPS curriculum framework is the collection of courses and concepts in D1.3. Based on this the consortium conducted workshops throughout the consortium meetings of the first year to create a concept and strategy to develop the MS@CPS study program.

3.1 Following the Bologna Process

Deliverable D1.4 collects the concept of the Bologna process and its defining factors. This deliverable acknowledges the conversion between credit hours (CHR) and credit points in the ECTS.

3.2 A Module-based Curriculum

WP 1 one introduced a sequence of actions to analyse CPS literature and existing CPS courses and study programs to identify study areas and state of the art topics of CPS systems as a theoretical foundation of the MS@CPS study program. This was followed by online and physical workshops as part of the first consortium meetings to identify communalities and study concepts that can support a high quality, yet flexible study program. As identified in section 1 of this document, many of the foundational areas of CPS are already today taught in distinct courses at local universities with a strong technical faculty. However, the mix, update and blending of the courses and course topics, together with creating practical spaces of application, is vital for a successful implementation.

All members of the MS@CPS project are experienced teachers and researchers in the field of CPS. Throughout the second consortium meeting the MS@CPS the team conducted a workshop to use the first results of the WP 1 actions to isolate the main composing areas of CPS to create study modules. These main modules are:

- **Embedded Systems:** Exploring the source CPS which described explicitly the blending of different disciplines to create highly complex electronic systems.
- **Safety and Security:** Complex systems are especially relevant in areas with systems that are critical in terms of one or more requirements as timing, physical resistance, energy efficiency and failure resistance, all while communicating with distributed systems. As such safety, security and dependability plays a major role to ensure the operation of such systems of systems scenarios.
- **Advanced Communication Networks:** With the advent of the internet of things (IOT) and time critical systems, the communication networks they operate on are becoming vitally important and need to be studied to create dependable and sustainable systems.
- **AI and Advanced Computing:** At the heart of the new information processing capabilities of modern CPS components, lies the ability to reason, locally or distributed, using smart algorithms and new concepts of learning systems. Here artificial intelligence (AI) and advanced computing concepts and a perspective of knowledge management are in the focus for CPS.
- **Entrepreneurship:** Taking a wider angle and accounting for the practical focus of the study program, the studies need a market perspective, along with base economical knowledge to exploit modern ideas of CPS on the markets.
- **Human Machine Systems:** Any complex system meant to support human production or productivity, needs concepts of interaction between systems or systems and humans. This upgrades network communication to networked services, which provide support and services to the human endeavours.

The respective modules are collected in the following in Table 1. The rational of the study plan and application in the local environments is given in the next section 3.3.

Table 1: The six modules of the MS@CPS study program, including the obligatory and elective courses.

Module Embedded Systems	Module Safety and Security
Core course/LOs: ▪ Embedded platforms (hardware and software) **Elective courses/LOs:** ▪ Real-time systems ▪ Sensors and actuators ▪ Control systems	**Core course/LOs:** ▪ Security (privacy, data integrity) **Elective courses/LOs:** ▪ Dependability (safety, reliability, availability)
Module Advanced Communication Networks	**Module AI and Advanced Computing**
Core course/LOs: ▪ Internet of things **Elective courses/LOs:** ▪ Distributed systems (open industrial) ▪ Cloud computing ▪ Low power networks ▪ Network optimization ▪ Industrial communication protocols ▪ Mobile communication networks ▪ Wireless communication networks	**Core course/LOs:** ▪ Machine learning **Elective courses/LOs:** ▪ Big data analytics ▪ Computer vision ▪ Optimization ▪ Theory and algorithms ▪ Software engineering ▪ Knowledge management
Module Entrepreneurship	**Module Human Machine Systems**
Core course/LOs: ▪ Innovation and entrepreneurship	**Core course/LOs:** ▪ Human machine interaction **Elective courses/LOs:** ▪ Mobile and ubiquitous computing ▪ Distributed control systems

3.3 From Modules to Learning Objectives – a new Objective-based Curriculum Perspective

The process of study programme design is traditionally a top-down process. Study programmes are clustered into areas which are represented by modules. Modules include courses and teaching tools as seminars, internships etc, which support the coverage of the modules content from a learning perspective. To express the coverage and the study level alike, each course defines a set of learning outcomes that describes the goals of the course in terms of the target of learning. As raised in section 2, learning outcomes, or learning goals do describe the outcomes in a more abstract manner, which enables an adaptability facing a progressing field, without the need of changing the outcomes, leading to a stable, yet evolving programme.

For MS@CPS it was evident based on the outcomes of WP 1, that a base level of required courses were available at the local level, covering a foundation of courses which needed to be adopted and updated in line with state-of-the-art works and aligned to the 2.1 MS@CPS pedagogy. However, not all courses had the same composition. I.e., learning outcomes of an identified course, could be distributed across two or more other courses, or selected courses could cover more than the intended learning outcomes, with a potential higher study load. Furthermore, the available courses were tailored to an expected level of excellence but also to local market requirements and local study cultures. In line with that the consortium defined the following goals:

- Align courses to a common quality level.
- Integrate local lessons learned and best practices, including well established topic compositions – if and only if they fit to the MS@CPS requirements.
- Create a course matching strategy to align and transform the local course structure and contents to the MS@CPS composition.

Based on this the consortium designed a novel MS@CPS study programme framework. Each study programme fundamentally breaks down into its composing learning objectives in a top-down perspective. However, taking then a bottom-up perspective the pool of learning outcomes could be used to support different course compositions, while still covering the intended overall set of learning outcomes. So rather than agreeing on fixed courses per module, the partners agreed on covering the set of learning outcomes that were defined by the course analysis of WP 1.

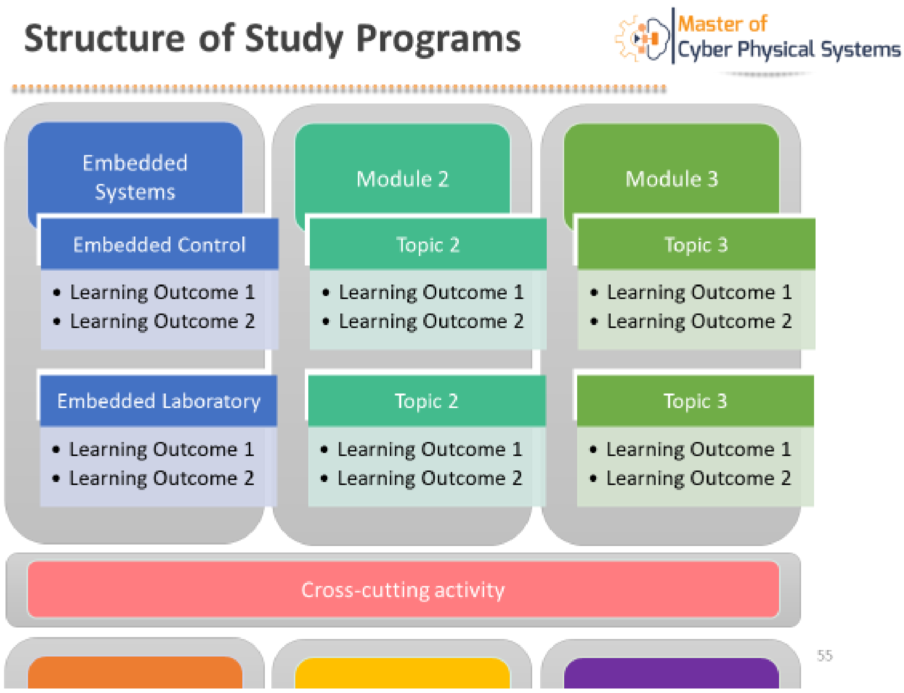


Figure 4: Traditional module-based programme composition.

Figure 4 shows the traditional module-based perspective on study programmes. To introduce a bigger flexibility, while keeping a cross-country comparability, the consortium implemented a multi-step strategy to construct the programme frame:

1. Identify relevant courses and learning outcomes for CPS studies globally.
2. Identify and add learning outcomes that are identified as vital from state-of-the-art and state-of-the-work articles and experiences.
3. Identify core areas of CPS and set them as modules with a compromise between separability of the domains and a reasonable number of modules to prevent a dissolving of the study focus.
4. Cluster the identified courses and therefore learning outcomes into the created modules.
5. Identify per each module the course that has to be mastered at minimum to master the base required learning outcomes per module and make the course a mandatory core course.
6. Collect all courses that are relevant from the pre-study for a given module and add them as elective courses.
7. Consider all courses as compositions of learning outcomes and mark the learning outcomes of the core courses as mandatory.
8. Collect and match all locally available courses with fitting learning outcomes to the courses and learning outcomes in the module.
9. Ensure that the mandatory course per module is matched in all its composing learning outcomes. Else create the course at local level.
10. Add all courses that match a sufficient number of learning outcomes that were identified as elective to the respective modules.
11. Ensure that the requirements for intersecting CPS domains throughout courses is met.
12. Ensure that the requirements for practical studies are fulfilled as defined in the D2.1 MS@CPS pedagogy.

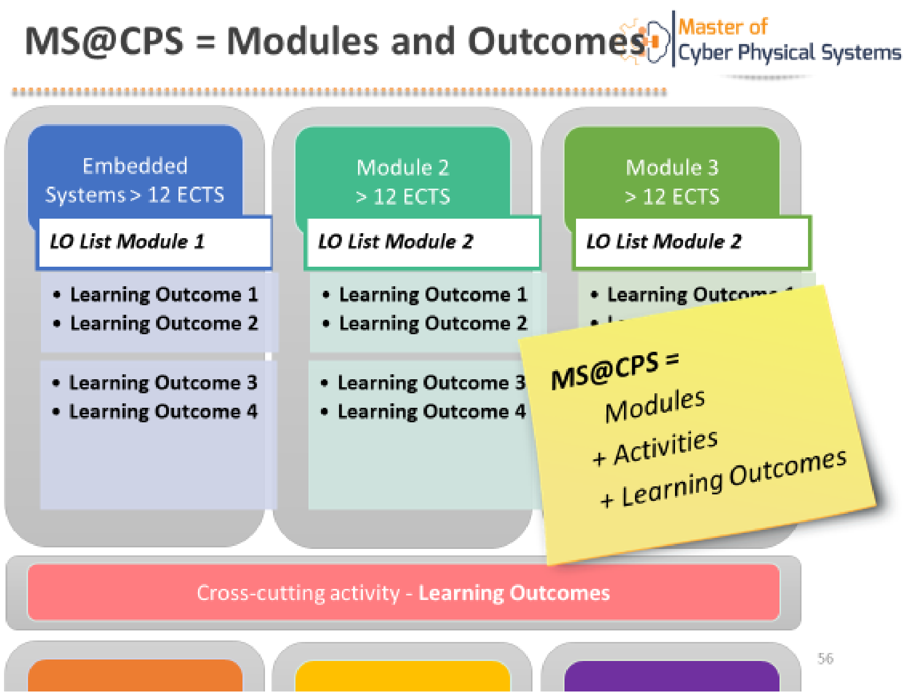


Figure 5: New MS@CPS programme perspective.

This leads to the study structure that is visualized in Figure 5, above. The base groups are the modules and for each module a fixed number of ECTS points is defined as a minimum number for being able to master the module. The exception is the module 5 “Entrepreneurship” which includes only one mandatory course and only one course overall.

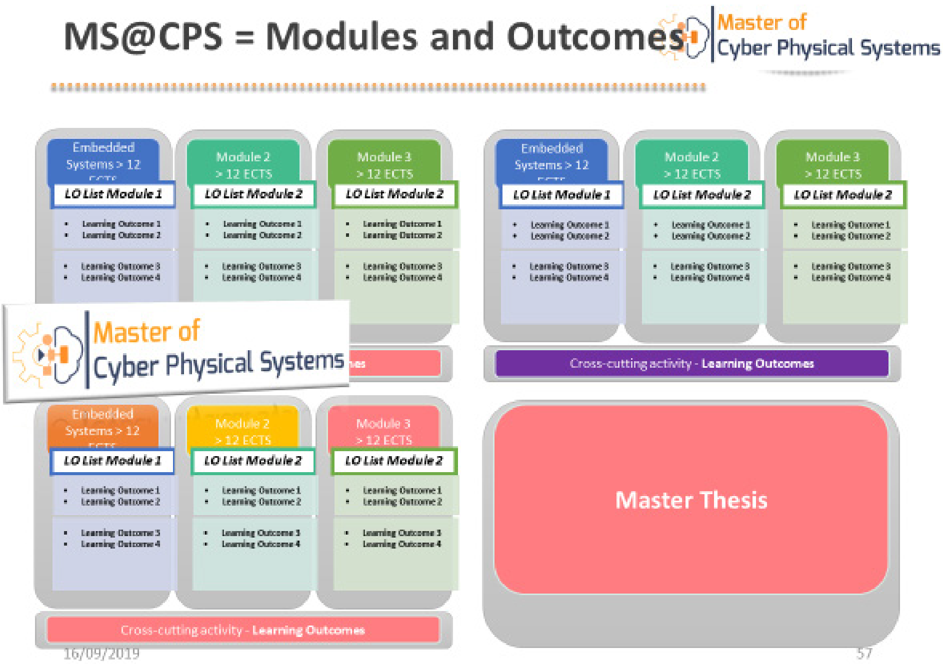


Figure 6: MS@CPS novel study programme composition.

Figure 6 shows a graphical representation of the strategy of the study programme. The graphic depicts a range of modules which together compose the study programme. Within each module practical activities are planned in line with the MS@CPS pedagogy. As the intent of the practical activities is to explore intersections between areas, such activities can be implemented as cross-cutting across multiple modules. This can be seen through the horizontal activity blocks. The master thesis is a projection-space of the mastered learning outcomes and serves as a scientific and practical exploration. As such it has a dominant position.

Across the partner-countries the conducting and frame of the master thesis can differ. Within the Bologna system, master thesis works are usually adding up to up to 30 credit points, sometimes accompanied with a specialized course that teaches the basics of research methodology to ensure a high quality of the finished works. Master thesis works are required to include a research component to enable a potential path towards a PhD programme. In partner-countries however the credit points and the framing of the thesis works can differ. I.e., the master thesis can be split into multiple stages with different outcomes or can require an additional course while reducing the base credit points of the master thesis work. Especially the later is motivated by a stronger industry focus.

Following the local training culture, the consortium compromised the requirements of thesis works and allowed the implementation of local solutions. However, the consortium agreed on implementing a 30 credit points equivalent solution as one of the local implementations available at each partner university, as well as agreeing on explicitly endorsing the selection of that solution for future students to minimize the manual recognition process in cases where master students want to pursue a PhD within European institutions. Furthermore, the consortium agreed to endorse conducting master thesis works locally either directly with industrial partners or developing master thesis topics together with the local industry, as expressed within the whitepaper within D2.1.

3.4 MS@CPS Branding and Transferability

Section 3.4 describes a flexible study programme for teaching CPS in higher education. This study programme is unique in its composition, combining the flexible approach with a bottom-up, learning outcomes-based framing and an explicit pedagogy that impacts the how of teaching and implementation. This together creates a flexible framework that is at the core of the MS@CPS studies, focused on transferability with respect to the local qualities, while ensuring an international level of quality and comparability. Therefore, the MS@CPS study programme has the right framework to be seen as a global initiative and brand. The consortium intends to open up the concept to enable other universities to implement CPS programmes under the flag of MS@CPS and with MS@CPS as a seal of quality. To be able to gain the MS@CPS brand seal new study programmes have to fulfil the guidelines defined in the deliverables of WP 2, as well as to fit to the minimal definition of learning outcomes per each module.

With this we envision a wider impact on local, regional and European levels turning the MS@CPS study programme from a master into an international base standard for CPS training.

4 MS@CPS Modules

Section 4 now collects in detail module descriptions and matches the base skills and competencies to selected learning outcomes of the courses of the module. As markets rapidly develop the match cannot be complete at any given time but this collection should give an indication about the base match and their respective composition, importance within the study programme and relevance of the matched skills, competencies and learning outcomes.

To support future MS@CPS programmes section 4.1 collects a template, along the rational of filling to define future modules along the MS@CPS framework.

4.1 Module Template

4.1.1 Module Description

Please describe in the following section the module.

Intended size: 0.75 - 1 page.

Content:

- Overall describe the concept of the module and how it relates to CPS.
- Consider in the statement how it is related with a scientific perspective:
  - CPS as a domain of research,
  - Publications,
  - development in the literature regarding the module contents,
- and with a practical, industrial perspective:
  - How has the industry changed and is changing in the fields of the module, showing the relevance of the module for CPS?
  - How are the skills/competencies relevant for the practical and R&D in the industry?
- Then please, if not addressed in the motivational 0.75-1 pages, write one paragraph per course within the module to indicate how the course contents are relevant for the module.

Module description…

4.1.2 Skills and Competencies

Please address in the following section the skills and competences that are vital as an outcome to the module.

Intended size: At least 5 skills and 5 competences.

Content: Please list skills and competencies for the module. We need at least one skill and one competency per course for each module. The skill/competency has a short name (e.g., "computer literacy") and a short description. Please, furthermore, rate the skills/competencies on a scale of 1 to 10, with 10 being "most important".

Skills/competencies and Learning Objectives are different, but it is needed to address in this section skills/competences that cover at least most of the LOs of the core course of the module.

Background to consider: Skills and competencies are different from the learning outcomes but very often overlap considerably. You can find the definitions we will use for skills/competencies here:

- Skill: https://ec.europa.eu/esco/portal/escopedia/Skill

Skill

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> *Working as a "civil airline pilot" requires the competence to combine knowledge on "emergency procedures" and "equipment malfunctions" with skills on "reading position coordinates" and "following the air route". This application of knowledge and skills takes place in a partly unpredictable setting where technical and organisational problems occur on a daily basis and where solutions have to be immediately identified and applied – either by the pilot alone or through team-working (e.g. involving the cabin crew or the ground staff).*

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In ESCO, competences are part of the skills pillar.

Skills

#	Skill name	Description	Relevance	Relevance Rating [1-10]	Related Course and LOs
	Short name like "Object oriented programming"	**A small paragraph describing the skill**	**Short statement on why is this relevant for a CPS curriculum?**	**8 (=high)**	**Software Engineering [LO1, LO3…], Machine Learning [LO4]**
1.					
2.					
3.					
4.					
5.					

Competencies:

#	Competence name	Description	Relevance	Relevance Rating [1-10]	Related Course and LOs
	Short name like "Structured Programming Thinking"	**A small paragraph describing the competence**	**Short statement on why is this relevant for a CPS curriculum?**	**8 (=high)**	**Software Engineering [LO1, LO3…], Machine Learning [LO4]**
1.					
2.					
3.					
4.					
5.					

4.1.3 Summary Statement

Short summary if needed and collect recommendations on how to design and apply this module in a future MS@CPS style study program. E.g. Do we need to work especially close with the industry? Should we integrate more practical classes or is it vitally important to lay some the theoretical foundations more thoroughly because they are beneficial for other modules?

4.2 Module Embedded systems [CU]

4.2.1 Module Description

An “embedded system” refers to an autonomous electronic and computer system dedicated to a precise task, often in real time, having a limited size and having a limited energy consumption. The natural evolution of this field with the current industrial revolution, called "Industry 4.0" gives birth to the CPS "Cyber physic System" hence the following definition of CPS: A CPS is an autonomous embedded system, equipped with sensors to perceive its sound. Environment, capable of acting on physical processes by means of actuators. The CPS is cooperating and reactive systems, in permanent interaction with their physical and virtual environment. Through CPS, embedded systems become connected, autonomous, or even “intelligent”, which makes it possible to manage new sources of value.

In summary, CPS as a module requires knowledge and skills in several underlying sub-fields included in the field of Embedded Systems. In fact, to design an embedded system, it is generally necessary to combine skills in electronics, industrial computing, and automation. Such systems are numerous in sectors as varied as aeronautics, household appliances, medical equipment, mobile telephony, etc.

The major topics in our module:

- Real-time system: we speak of a real-time system when this system is capable of controlling (or piloting) a physical process at a speed adapted to the evolution of the controlled process.
- Actuators and Sensors constitute the operational part of a CPS:
  - Actuators execute the orders received. They act on the system or its environment.
  - Sensors react to the state of the system or its environment. They report a state of the system.

Control system: a control system of an industrial process equipped with algorithms for the control and supervision of a system.

4.2.2 Skills and Competencies

Skills

#	Skill name	Description	Relevance	Relevance Rating [1-10]	Related Course and LOs
1.	Communication Protocol knowledge	Analyse the role of communication protocols in causing different entities to communicate	CPS is in the core of interaction between entities using communication protocols	8	SENSORS AND ACTUATORS[LO.2]
2.	Analog and Digital hardware design	Ability to design a project integrating analog and/or digital hardware	CPS as an embedded system require the capacity of designing analog and hardware parts	8	Embedded Platforms (Hardware & Software) [LO.4], SENSORS AND ACTUATORS[LO.2],
3.	Control system Comprehension	understanding of how Control Systems work (Process Management, Memory management)	strong ability to analyse and understand a CPS system	7	Control systems [LO.2]
4.	Control algorithm understanding	Ability to develop and apply control algorithms in industrial systems (Matlab, Simulink)	Student should be able to develop and apply algorithms in systems	8	Control systems [LO.1], Real Time Systems [LO.1, LO.2, LO.4]
5.	Industrial system modelling	Knowledge of modelling and simulation of complex systems, power electronics, electromechanical actuation systems, knowledge of motor control applications problems	Students should be able to model and simulate functional parts that could form a CPS,	8	Control systems [LO.5]

Competencies:

#	Competence name	Description	Relevance	Relevance Rating [1-10]	Related Course and LOs
1.	Technical expertise	Expertise in the field of electronics, automatics	Students should have a technical background dealing with electronics and automatics.	7	Control systems [LO.1, LO.2, LO.3]
2.	Technical analysis	Able to read and interpret simulation through analysing results and outputs	CPS study requires a huge capacity in analysing and interpreting simulations	7	Real Time Systems [LO.3, LO.4, LO.5]
3.	Collaborative work	Ability to work in teams in order to coordinate work and tasks	CPS system involves different parts interacting that's why it is essential to ensure collaboration with different CPS-level parts professionals	6	Embedded Platforms (Hardware & Software [LO.2,..., LO.4]
4.	Learning capacity	Having the capacity to learn new protocols, new systems …	CPS is in continuous evolution; CPS professional should be up to date by learning about	8	SENSORS AND ACTUATORS [LO.3, LO.4], Real Time Systems [LO.2, LO.4, LO.5]
5.	Autonomous	Ability to work independently in some cases and to react rapidly facing a system failure for example	CPS are complex system that can undergo sudden a malfunction seeing that they are complex and large, CPS pro should react rapidly and autonomous in taking decision	7	Control systems [LO.1, LO.2, LO.3], Real Time Systems [LO.1]

4.2.3 Summary Statement

None.

4.3 Module Advanced communication networks [PTC]

4.3.1 Module Description

Cyber physical systems (CPSs) are orchestrations of computers, machines, and people working together to achieve goals using computation, communications, and control (CCC) technologies. CPSs consist of embedded computers and complex software applications networked together through wired and wireless links. These will be a part of all products and services and will allow the connection of large amounts of systems in their environment, either physical or at the cyber-space level, in real time.

Communication is an important issue in CPS systems, and it is therefore represented by a set of courses that fall under the *advanced communication networks module* which covers different aspects of communication topics. It is concerned with courses that focus on the communication principles, concepts and applications in CPSs. It includes Internet of things, Distributed systems, Cloud computing, Low power networks, Network optimization, Industrial communication protocol, Mobile communication networks, and Wireless communication networks. All titles of courses that falls within this module are active research topics. In fact, IoT is a trending research topic.

This module contains a set of overlapping courses. Internet of Things is about connecting "Things" (Objects and Machines) to the internet and eventually to each other; while CPSs are integration of computation, networking, and physical process.

On the other hand, a typical distributed embedded system such as a commercial building's lighting or heating system or an enterprise control system is never on the public Internet for obvious IT security reasons. Distributed systems and IoT might look similar; however, they differ in how open the network is. If a system is a closed network that operates in an isolated environment, it is a distributed embedded system.

WSN are networks of embedded devices, such as sensors, that have limited power, memory, and processing capability. These low-cost devices are often battery operated and can only handle limited amounts of data. Applications of WSN include the Internet of Things (IoT), Machine to Machine (M2M) communications, and Smart City. This course is related to the communication module through focusing on wireless protocols and internet connectivity.

Network Optimization course presents a modern theory of optimization for dynamic networks. It focuses on computer and wireless networks, including networks with time varying channels, mobility, and randomly arriving traffic. This course is related to the communication module through focusing on optimizing networks which is essential communication structure.

Industrial Communication Protocols course focuses on industrial automation networks. In this course major differences between industrial networks and traditional computer networks are considered in detail. This course is related to the communication module through focusing on applying communication protocols and techniques in industrial applications.

Mobile communications course presents the evolution of the mobile generation technology and introduces the multiple access techniques. The cellular concept is also discussed in detail featuring frequency reuse, channel allocation strategies, interference management, handoff strategies, power control, traffic intensity, and cellular capacity improvement techniques. This course is an essential communication module because mobile communications is a major economic sector in any country.

Wireless Communication Networks course describes the technology and standards with an emphasis on satellite communication networks, cellular wireless networks, cordless systems and Wireless Local

Loop, Mobile IP and Wireless Access Protocol, Wireless Local Area Networks Technology (WLANs), Wi-Fi and IEEE Wireless LAN Standards, Bluetooth and IEEE Standards, Personal Area Networks (PANs) and Ad hoc networks.

4.3.2 Skills and Competencies
Skills

#	Skill name	Description	Relevance	Relevance Rating [1-10]	Related Course and LOs
1.	Apply theory in practical systems	Demonstrate the ability of applying theory in practical CPS systems	The CPS is an applied engineering topic that has many theories behind it and the student should be able to connect theories with practical concepts.	9	Internet of Things [LO 5] Distributed Systems [LO 5] Low Power Networks [LO 5] Network Optimization [LO 4] Industrial Communication Protocols [LO 3] Mobile Communication Networks [LO 4] Wireless Communication Networks [LO 4]
2.	Understand the main principles of wireless and mobile communication systems	Demonstrate an understanding of wireless and mobile communication systems in the field of CPS	Basic understanding of wireless and mobile communications systems in CPSs is essential for developing innovative CPS systems.	9	Internet of Things [LO 7] Low Power Networks [LO 1] Mobile Communication Networks [LO 1-6] Wireless Communication Networks [LO 2] [LO 5] [LO 6]
3.	Understanding of sensor concepts in CPSs	Demonstrate an understanding of sensors role in the field of CPS.	Basic understanding of sensors in CPSs is essential for developing innovative CPS systems.	9	Internet of Things [LO 3] Low Power Networks [LO 1] Industrial Communication Protocols [LO 7]
4.	Understanding of the IoT applications and routing protocols in CPSs	Demonstrate an understanding of the IoT applications and routing protocols in the field of CPS.	Basic understanding of IoT, routing protocols and their applications in CPSs is essential for developing innovative CPS systems.	9	Internet of Things [LO 1] [LO 3] [LO 4] [LO 5] Low Power Networks [LO 4] Industrial Communication Protocols [LO 2]
5.	Research Skills	Demonstrate an understanding of recent research issues in the field of CPS.	It is necessary that students acquire skills in order to conduct research during their studies	8	Low power networks [LO 7] [LO 6] Mobile and Ubiquitous Computing [LO 1, LO2]

Competencies:

#	Competence name	Description	Relevance	Relevance Rating [1-10]	Related Course and LOs
1.	Critical Thinking	Competency in critical thinking addresses a student's ability to analyze information and ideas from multiple perspectives and articulate an argument or an opinion or a conclusion based on their analysis.	CPS systems require the ability to analyse and make a conclusion about the system	7	Industrial Communication Protocols [LO 2] Mobile Communication Networks [LO 5] [LO 6]
2.	Problem Solving	Competency in problem solving represents a student's ability to design, evaluate, and implement a strategy to answer a question or achieve a goal.	CPS systems require this competency either in developing new systems or troubleshooting failed systems.	9	Internet of Things [LO 4] Distributed Systems [LO 7] Low power networks [LO 3] Network Optimization [LO 1] [LO 4] [LO 6] Mobile Communication Networks [LO 4] Wireless Communication Networks [LO 1]
3.	Information Literacy	Information literacy refers to the set of skills needed to find, retrieve, analyse, and use information. Competency in information literacy represents a student's ability to know when there is a need for information, to be able to identify, locate, evaluate, and effectively and responsibly use that information for the task or problem at hand.	CPS experts should be able to identify, evaluate complex systems		Distributed Systems [LO 5] Low power networks [LO 6] Mobile Communication Networks [LO 3] [LO 4]
4.	Quantitative Literacy	Competency in quantitative literacy represents a student's ability to use quantifiable information and mathematical analysis to make connections and draw conclusions. Students with strong quantitative literacy skills understand and can create sophisticated arguments supported by quantitative evidence and can clearly communicate those arguments in a variety of formats (using words, tables, graphs, mathematical equations, etc.).	In CPS systems math play an important role in making conclusions about their performance.	7	Mobile Communication Networks [LO 5]
5.	Inquiry & Analysis	Inquiry is a systematic process of exploring issues/objects/works through the collection and analysis of evidence that results in informed conclusion/judgments. Analysis is the process	CPSs are complex systems and breaking them into parts gives better understanding of their work.	7	Mobile Communication Networks [LO 5]

		of breaking complex topics or issues into parts to gain a better understanding of them.			

4.3.3 Summary Statement

Module courses should be updated regularly because some courses are technology dependent and nowadays technology is changing rapidly. These rapid changes necessitate that few courses should be closely related to industry because in CPS filed the industry drives the development of technology. The study plan and courses contents should be updated regularly to keep pace with the trending topics in the field of CPS. Meanwhile, industry shapes the trending topics in the CPS based on society needs. A good example can be the growth of mobile communication networks. With more involvement of society in internet applications, there becomes a need for higher speed communications to serve mobile internet applications. We recommend to keep the balance in all modules between including the theoretical foundations of communications principles and the practical part. The theoretical foundations give the student the ability to understand the new developments in the communications field. One the other hand, the practical part links the needed skills and competencies for the industry with what the student have learnt theoretically.

4.4 Module Entrepreneurship [GJU/KTH]

4.4.1 Module Description

The project introduces a new master program in IT files with focus on Cyber-Physical Systems (CPSs). Entrepreneurship for engineers is an integrating course on the basics of entrepreneurship and innovation management. The course focuses on specialised understanding of aspects as idea generation, technology-based entrepreneurship, marketing and markets, organisation and project management, new product and process development, entrepreneurship, finance, and human resource development.

The participants will become acquainted with the tools and practices of the entrepreneur and will learn how to develop as well as critically analyse and assess business ideas, business models and business plans.

The course is aimed towards those students that one day will start their own businesses, as well as towards those students that one day will work together with an entrepreneur, perhaps even be responsible for deciding whether or not to finance an entrepreneur's business idea. The importance of being able to evaluate the proposals of entrepreneurs is therefore an extensive part of the course. The course also addresses critical enterprise planning and building skills, backed by both theory and practice.

We challenge students to identify problems or needs, generate innovative ideas, evaluate, and improve them, and begin laying the groundwork for compelling business plans and the launch of dynamic enterprises.

The course is carried out through lectures, digital e-learning modules, idea-screening, group projects and a final individual work.

The major topics in this module can include:

- An understanding of the nature of innovation and entrepreneurship and the potential inherent in these, including theories of how they function, how they can be managed and how to find novel ways to realise projects in the economy.
- The necessary skills to start and manage projects of an innovative nature, including skills in business model innovation and executing new projects and start-ups. This also includes critical skills for the effective leader in a contemporary economy, such as creativity, communication, and presentation.
- A set of critical skills needed to properly analyse and assess innovative projects, as well as the theoretical basis upon which the participants can build their further development as innovation leaders.

4.4.2 Skills and Competencies

Skills

#	Skill name	Description	Relevance	Relevance Rating [1-10]	Related Course and LOs
1.	Project Management	Ability to (lead/be a member) of the work to achieve the planed objectives and goals following the specified criteria and time plan.	The graduate of the CPS program requires to work in projects environment as a leader or team member	8	Entrepreneurship [All LO]
2.	Leadership and communication	Ability to work in team environment, where you can ask, listen, communicate and receiving and Implementing Feedback.	The graduate of the CPS program requires such knowledge to achieve the work task and team engagement.	8	Entrepreneurship [All LO]
3.	Research Skills	Demonstrate an understanding of recent research issues in the field of CPS.	It is necessary that students acquire skills in order to conduct research during their studies	8	Entrepreneurship [All LO]
4.	Tools to lead new business ventures and start-ups.	The ability to use modern technologies to develop systems under different constraints and for different environments	New Technology and skills is an essential component of CPS graduates and start-up business	8	Entrepreneurship [All LO]

Competencies:

#	Competence name	Description	Relevance	Relevance Rating [1-10]	Related Course and LOs
1.	Evaluation Techniques	To identify problems or need for new design and evaluation methods	CPS student should be able to perform evaluation of complex systems and needs	8	Entrepreneurship
2.	Knowledge Integration	The ability to integrate knowledge, and to analyse, assess and manage information based on the task and project needs	Ability of the CPS student to generate innovative ideas, evaluate and improve them, and begin laying the groundwork for compelling business plans and the launch of dynamic enterprises.	8	Entrepreneurship
3.	Professional Competencies	Implement the new competence such as business model innovation and executing new projects and start-ups in project or industry.	Professional competencies are needed in the design and implementation of CPS knowledge to start up business or join the industry as team member or leader.	8	Entrepreneurship
4.	Business and financial competence	Ability to describe and compare different financing options for entrepreneurs.	compile, present and analyse empirical research in entrepreneurship and innovation.	8	Entrepreneurship

4.4.3 Summary Statement

None.

4.5 Module Safety and Security [TTU]

4.5.1 Module Description

Cyber-physical systems (CPSs) have proliferated into several domains and applications to enable process optimization**.** CPSs are resulting from a seamless integration between networked digital systems and analog physical processes. This combination creates unique characteristics that change how security and safety practices are applied. Security and safety in Cyber-Physical Systems are one of the most critical issues facing the research and development community.

Security and safety have a profound influence on the effectiveness of the applicability of CPSs in numerous critical applications in a wide spectrum of fields, such as automotive, chemical processes, healthcare, civil infrastructure, consumer appliances, energy, entertainment, manufacturing, transportation, and so forth. In the years ahead, Secure CPSs will drive innovation and competition across the aforementioned industry sectors.

Therefore, we should take into account the cyber and physical security and safety aspects together to protect CPSs because the cross-over effects can introduce unexpected vulnerabilities. Due to these vulnerabilities, Due to these vulnerabilities, the CPSs are being targeted by many cyber and physical attacks which can cause sever security and safety threats, which may result in system failure or privacy infringement. For example, Physical attacks may destruct or compromise sensitive information being processed by the devices (such as sensors and actuators), while cyber-attacks may cause physical malfunctions resulting in real-world consequences.

The effective security and safety solutions in CPSs can lead to prevent any unexpected harm on systems and users. Therefore, security and safety are key concerns for CPS design, development, and operation. In this module, we focus on how CPS security and safety differ from that of pure cyber or physical systems and what may be achieved to protect these systems. According to the existing research studies, the research relating to the security and safety of CPSs has become one of the hot research topics that recently drawn the attention of academia, industry, and governments because of its wide impact on society, economy, and the environment in case of systems failures. Therefore, the recent scientific research and education, such as the security and safety module, focuses on providing students with essential skills and competencies of emerging CPS to develop more secure, privacy-enhanced tools and technologies in the future.

4.5.2 **Skills and Competencies**
Skills

#	Skill name	Description	Relevance	Relevance Rating [1-10]	Related Course and LOs
1.	Emerging new security practices and solutions	The ability to emerge new security technologies, apply effective solutions, and follow the best practices and standards to protect the CPS infrastructure (network, hardware, and software) and its massive data from possible attacks.	To keep the CPSs protected, we have to emerge always new security practices and solutions	9	Security and Privacy [LO2, LO3, LO7] Dependability (Safety, Reliability, Availability) [LO2, LO4]
2.	Communication skills	The ability to communicate effectively in both written and verbal ways and explain the security and safety issues, concerns, and technical solutions to individuals in other departments with different technical levels. Also, the security and safety specialist should be able negotiate the security policy and strategy with non-technical individuals.	CPS protection requires professionals with high verbal and writing reporting skills to facilitate the communications with others.	8	Security and Privacy [LO1, LO3, LO10] Dependability (Safety, Reliability, Availability) [LO2, LO4]
3.	Technical qualifications	The ability to perform effectively the daily activities such as troubleshooting, maintaining, and updating information security systems; implementing continuous network monitoring; and providing real-time security solutions.	The CPSs protection need qualified professionals in security and safety field	8	Security and Privacy [LO5, LO6, LO9] Dependability (Safety, Reliability, Availability) [LO1, LO5]
4.	Awareness of security and safety across various computing platforms	The ability to work in comfortable way on a variety of operating systems, computer systems, mobile devices, cloud networks, embedded systems, and wireless networks - and keep up to date on advances in the security and safety domain for all of them	Several operating systems are working together in CPS. So, it is necessary for security specialists to have a solid knowledge in OS platforms.	8	Security and Privacy [LO5, LO6] Dependability (Safety, Reliability, Availability) [LO1, LO4]
5.	Research skills	The ability to conduct research studies, evaluations, and construct real case studies in the security and safety field in order to find solutions of security and safety issues.	New security and safety issues in CPS are arisen. This is required to be studied by individuals with good research skills.	8	Security and Privacy [LO4, LO8], Dependability (Safety, Reliability, Availability) [LO3, LO5, LO6]
6.	Application security development	Ability to improve the security of any application by finding, fixing, and preventing its vulnerabilities. In addition, the security specialist have programming and development skills to test and validate the required application during the software development lifecycle (secSDLC) so that vulnerabilities are addressed before an application is deployed	Cyber physical systems as any system need to be validated and tested during the development process to avoid any system failures later.	7	Security and Privacy [LO4] Dependability (Safety, Reliability, Availability) [LO1, LO4, LO5]

Competencies:

#	Competence name	Description	Relevance	Relevance Rating [1-10]	Related Course and LOs
1.	Collaborative practice	Security and safety of CPS is a shared responsibility across all individuals, in different levels, who are working in the CPS. Therefore, the security and safety specialists are collaborative and work with others in CPSs to setup a culture of security and safety. They make sure security policies are followed in correct way.	To protect CPSs, it is necessary for security specialists to collaborate with others	8	Security and Privacy [LO3,LO5] Dependability (Safety, Reliability, Availability) [LO4]
2.	Analytical analysis and problem solving	Analytical analysis and problem-solving play a significant role in the daily operations for security and safety specialists. Those in the field need to find creative ways to take on and address complex information security and safety challenges across a variety of existing and emerging technologies and digital environments.	CPSs are large scale systems, which introduce security, privacy, and safety problems that need decision makers with high problem-solving skills.	9	Security and Privacy [LO4,LO6, LO8] Dependability (Safety, Reliability, Availability) [LO3, LO6]
3.	Security and safety management	The ability to manage the security team, manage security and safety technologies and solutions, and manage the risk process. In addition, security and safety specialists are able to perform all the associated duties in ethical and legal manner.	It is necessary to manage security and safety process in heterogeneous platforms such as CPSs	8	Security and Privacy [LO9, LO10] Dependability (Safety, Reliability, Availability) [LO6]
4.	Security and safety assessment techniques	To be able to assess the existing and new security and safety techniques and solutions through following different types of security and safety evaluations and the required components of a security and safety assessment process	It is necessary to conduct continuous assessment of security and safety aspects in CPS field	9	Security and Privacy [LO4, LO8, LO9] Dependability (Safety, Reliability, Availability) [LO3, LO6]
5.	Ethical, social, and legal awareness	Ability to take into accounts the legal and ethical aspects, standards, and principles when developing CPSs and its impact on society. Where the CPS failures may lead to disastrous consequences for society.	The CPSs must be developed that take into consideration the privacy protection, intellectual property, and reference standards.	8	Security and Privacy [LO5] Dependability (Safety, Reliability, Availability) [LO5]

4.5.3 Summary Statement

This course will be more beneficial for student if the course topics are integrated with industry. We plan to search some agencies and companies, which their expertise and work in security and privacy fields. It is recommended for students to have technical training in this domain from well-known academic centres. Furthermore, this course will be interesting if the practical and theoretical classes offered during the semester. There are many tools and software can be involved in this course to provide students with a good practical knowledge and skills. Moreover, it recommended inviting an expert in the security and privacy domain to share his expertise with students. Security and privacy issues are hot topics in the most other topics covered by other courses. Therefore, if the student has a solid background in security and privacy, he will be able to perform some research in e.g., IoT, Embedded systems, Networks, software engineering, and dependable systems with focusing on security and privacy issues in these fields. The suggested practical and theoretical topics in this course can be a seed to deliver a new master program in the security and privacy of CPS field.

4.6 Module AI and advanced computing [USF]

4.6.1 Module Description

Artificial intelligence has become critical technologies in information security, as they are able to quickly analyse automatically millions of events and identify many different types of threats like malware classification or the identifying of intrusion detection.

In fact, there is a big range of interdisciplinary intersections between cyber security and artificial intelligence fields. Artificial intelligence (AI) can be used into cyber security to construct smart models for implementing malware classification and intrusion detection and threating intelligence sensing. Also, AI models will face various cyber threats, which will disturb their sample, learning, and decisions. Thus, AI models need specific cyber security defence and protection technologies to combat adversarial machine learning, preserve privacy in machine learning, secure federated learning, etc. In this context, there are several research efforts in terms of combating cyber-attacks using AI, based on traditional machine learning methods or deep learning solutions.

As application of Machine learning, we specify the anomaly detection methods, which are already effective defence mechanisms against known network intrusion attacks, have also proven themselves to be more successful on the detection of zero-day attacks compared to other types of detection methods. Therefore, research on network anomaly detection using deep learning is getting more attention constantly.

For example, in the field of Computer Vision, it has become the workhorse for applications ranging from self-driving cars to surveillance and security. Recent studies show that they are vulnerable to adversarial attacks in the form of subtle perturbations to inputs that lead a model to predict incorrect outputs. For images, such perturbations are often too small to be perceptible, yet they completely fool the deep learning models. Adversarial attacks pose a serious threat to the success of deep learning in practice. Research shows that that designs adversarial attacks, analyse the existence of such attacks and propose defences against them.

Also, from a software view, a range of common components are gradually being integrated into the infrastructures that support safety-critical systems. The increasing use of these software components creates concerns that bugs might affect multiple systems across many different safety-related industries. It also raises significant security concerns. Malware has been detected in power distribution, healthcare, military, and transportation infrastructures. Most previous attacks do not seem to have deliberately targeted critical applications. However, there is no room for complacency in the face of increasing vulnerability to cyber-attacks on safety related systems.

4.6.2 Skills and Competencies

Skills

#	Skill name	Description	Relevance	Relevance Rating [1-10]	Related Course and LOs
	Short name like "Object oriented programming"	**A small paragraph describing the skill**	**Short statement on why is this relevant for a CPS curriculum?**	**8 (=high)**	**Software Engineering [LO1, LO3…], Machine Learning [LO4]**
1.					
2.					
3.					
4.					
5.					

Competencies:

#	Competence name	Description	Relevance	Relevance Rating [1-10]	Related Course and LOs
	Short name like “Structured Programming Thinking”	**A small paragraph describing the competence**	**Short statement on why is this relevant for a CPS curriculum?**	**8 (=high)**	**Software Engineering [LO1, LO3…], Machine Learning [LO4]**
1.					
2.					
3.					
4.					
5.					

4.6.3 Summary Statement

Short summary if needed and collect recommendations on how to design and apply this module in a future MS@CPS style study program. E.g. Do we need to work especially close with the industry? Should we integrate more practical classes or is it vitally important to lay some the theoretical foundations more thoroughly because they are beneficial for other modules?

4.7 Module Human/Machine Systems [AQU]

4.7.1 Module Description

Cyber-Physical Systems (CPSs) plays a major role in the design and development of current and future engineering systems. Major aspects of cyber-physical systems design require professionals in the areas of integrative systems design, Human-Computer Interaction (HCI), Distributed control systems, Mobile and Ubiquitous Computing Information Assurance and Security (IAS), Reliability, Networking, Web Interactions, and much more. Most of these skills are part of the pillars and central themes of IT education, while the main CPS research areas (generic architecture, design principles, modelling, dependability, and implementation)

Human/Machine System module is concerned with designing interactions between human activities and the computational systems that support them, with constructing interfaces to afford those interactions, and with the study of major phenomena surrounding them. Interaction between users and computational artifacts occurs at an interface which includes both software and hardware. Thus, interface design impacts the software life cycle in that it should occur early; the design and implementation of core functionality can influence the user interface for better or worse. HCI draws on a variety of disciplinary traditions, including psychology, ergonomics, computer science, graphic and product design, anthropology, and engineering.

Emphasis will be on the practical understanding, application and evaluation of HCI concepts and methods.

On the other hand, CPS, such as large manufacturing facilities, are human-centric. Human-machine systems-oriented issues arise at different levels: System, Computing and Interaction. These systems interact with a considerable number of distributed computing elements for monitoring, control and management which can exchange information between them and notably with humans. Such complex systems are of crucial importance in industry and though play major role in the country economy.

Major topics in this module can include:

- Cyber Transportation and Human Interaction in Connected and Autonomous Vehicles
- Human-centric Internet of Things: Interaction between Humans and Smart Objects
- Smart Communities living in Smart Cyber-physical Worlds.
- Human Manipulation of Motorized Cyber-Physical Systems
- Co-existence and cooperation of Humans and Robots in Smart Environments

4.7.2 Skills and Competencies

Skills

#	Skill name	Description	Relevance	Relevance Rating [1-10]	Related Course and LOs
	Short name like "Object oriented programming"	A small paragraph describing the skill	Short statement on why is this relevant for a CPS curriculum?	8 (=high)	Software Engineering [LO1, LO3…], Machine Learning [LO4]
1.	Information Synthesizes	Ability to synthesize information from a variety of sources and present conclusions clearly, both in written form and using easy-to-understand visuals (graphs, charts, diagrams, flow charts, wireframes	The design of CPS requires the interface of complex systems and this requires the ability to synthesizes information.	8	Human Computer interaction [LO1, LO4, LO7,LO9]
2.	Technology Awareness	Ability to keep up with new advances in technology in different domains such a manufacturing, software engineering, intelligent systems, …) as well as a great understanding of the capabilities of different kinds of computing devices such as desktop, tablet, smartphone, smart watch, touch screens, wearable devices, etc.	CPS design requires knowledge of new kind of devices that are always developing and updated.	8	Human Computer interaction [LO3, LO6]
3.	Control logic and Control processes Understanding	The ability to understand how process control, information flow, and decision-making in distributed systems	It is important in in modern-day DCS is the integration with ERP and IT systems through exchange of various pieces of information	7	Distributed Control Systems [LO4, LO5]
4.	Mobile and ubiquitous Systems Development	The ability to use modern technologies to develop in mobile and ubiquitous systems under different constraints and for different environments	Mobile and Ubiquitous computing systems is an essential component of CPS.	8	Mobile and Ubiquitous Computing [LO 7]
5.	Research Skills	Demonstrate an understanding of recent research issues in the field of CPS.	It is necessary that students acquire skills in order to conduct research during their studies	8	Human Computer interaction [LO 2, LO8] Distributed Control Systems [LO 6] Mobile and Ubiquitous Computing [LO 1, LO2]

Competencies:

#	Competence name	Description	Relevance	Relevance Rating [1-10]	Related Course and LOs
	Short name like "Structured Programming Thinking"	A small paragraph describing the competence	Short statement on why is this relevant for a CPS curriculum?	8 (=high)	Software Engineering [LO1, LO3…], Machine Learning [LO4]
1.	Evaluation Techniques	To master new design and evaluation methods and new technical competencies.	CPS designers should be able to perform evaluation of complex systems	8	Human Computer interaction [LO8]
2.	Knowledge Integration	The ability to integrate knowledge and to analyse, assess and manage complex phenomena, questions and situations under conditions of limited information	CPS involves the design of complex systems that are from different domains, so it is necessary to be able to integrate such system under different circumstances	8	Human Computer interaction [LO4, LO6]
3.	Professional Competencies	To develop technical personnel skills and competences for Plant / Process Engineers, Control Room Operations, maintenance, and System Administration	Professional competencies are needed in the design and implementation pf CPS	7	Distributed Control Systems [LO2, LO4, LO5]
4.	Collaborative Working	To be able to communicate multidisciplinary and collaborate in diverse and multidisciplinary teams and be able to work with professional colleagues and users of information technological systems to represent and present the content and problems using modern presentation technologies and the writing of scientific reports and statements.	CPS involves working in teams of multidisciplinary professional and requires communication competencies	8	Mobile and Ubiquitous Computing [LO 1, LO2, LO3]
5.	Ethics and Legal Awareness	To be able to recognize and consider the legality and the underlying principles of systems to be designed as well as the understanding of how the consequences of the implementation of such system might impact society.	It is important that CPS confirms to ethical and legal frameworks	7	Mobile and Ubiquitous Computing [LO2, LO7]

4.7.3 Summary Statement

Human/Machine System module is concerned with designing interactions between human activities and the computational systems that support them. HCI draws on a variety of disciplinary traditions, including psychology, ergonomics, computer science, graphic and product design, anthropology and engineering.

Major topics in this module can include: Cyber Transportation, Internet of Things; Smart Communities, Human Manipulation of Motorized Cyber-Physical Systems, and Co-existence and cooperation of Humans and Robots in Smart Environments.

This module should be designed and implemented with more emphasis on case studies and workshops that involves the collaboration with industry. It is recommended to use real industrial case studies drawn from actual existing and future systems.