



MECHATRONICS AS A FRAMEWORK FOR DEVELOPING AND STANDARDISING ENGINEERING COMPETENCES IMPORTANT FOR SECURITY ENGINEERS

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ABSTRACT: *The presented paper deals with the identification and evaluation of engineering competences that are important for security engineering. The skills are considered from the multidisciplinary field mechatronics, which plays a critical role in addressing crises and security challenges in the modern world. Presented results are outcomes from the international project entitled MISCE - Mechatronics for Improving and Standardising Competences in Engineering.*

KEYWORDS: *Digital competences. Mechatronics. Certification and validation of competences. Security engineers.*

INTRODUCTION

Mechatronics is a multidisciplinary field combining mechanical engineering, electronics, computer science, and control systems. It plays a critical role in addressing crises and security challenges in the modern world. The University of Žilina, Faculty of Security Engineering, is one of the partners of an international project co-funded by the Erasmus+ Programme with the title “*MISCE – Mechatronics for Improving and Standardising Competences in Engineering*” (Project Number: 2022-1-ES01-KA220-HED-000089155).

The project has a duration of 36 months, starting 1st September 2022 and ending 31 August 2025. The project consortium consists of a polytechnic and universities from five different countries, grouped into two types. The project coordinator is the University of Castilla-La Mancha (Spain), with the other partners, namely Università degli Studi di Cagliari (Italy), Università degli Studi di Cassino e del Lazio Meridionale (Italy), ICEP s.r.o (Slovakia), Universidade do Minho (Portugal), Politechnika Rzeszowska (Poland), and Universitat Politècnica de València (Spain), pursuing the goals of the project.

The project aims to share knowledge, design and develop an infrastructure to support and train higher education teachers, creating a systematic framework so that university teaching and training systems and materials can be streamlined and shared. The goal of the project is also to fill the gap between academia and companies. Objectives of the project are: (i) strengthening partnerships and exchanging good practices in mechatronics engineering, (ii) increasing digital upskilling of European professionals to build the competencies needed to keep pace with fast-moving digital technology developments, (iii) closing the gender gap in STEM (Science, Technology, Engineering, and Mathematics), (iv) boosting sustainable economic growth and competitiveness by reinforcing innovation capacity, and (v) integrating the Knowledge Triangle.

The development of the project was divided into 5 work packages to achieve the outcomes of the project: (i) a better level of acquisition of technical competencies in engineering degrees, (ii) the integration of professionals from a specific sector in measuring the competencies, (iii) creation of a network for a continual improvement process in the acquisition of competencies, and (iv) standardisation of good practices in engineering degrees.

Table 1 Organisation of the project MISCE

N° of work packages (WP)	Name of work packages	Outcomes/tasks
1	Project Management	<ul style="list-style-type: none"> • To create and implement the quality plan • To organise the regular meetings of the consortium • To monitor budget implementation and outputs by analysing the project progress concerning the planned activities • Constantly tracking of the scientific, technical and administrative development of the project
2	Identification of engineering competences	<ul style="list-style-type: none"> • To analyse the engineering degrees to be handled in the project • To create the list of technical competences to be analysed • To quantify the level of the acquisition of the analysed competences • To create the final list of the competences to be improved in the project
3	Development of teaching material and digital repository	<ul style="list-style-type: none"> • To create the documentations – Preliminary Design Review (PDR) of the different devices, which is a technical assessment that establishes the allocated baseline of the device to ensure a system is operationally effective, Critical Design Review (CDR) of the different devices, which is a multidisciplinary technical review to ensure that a system can proceed into fabrication and demonstration • To create the real repository
4	Competences monitoring and reengineering	<ul style="list-style-type: none"> • To measure the level of competence acquisition • To improve the devices and its corresponding documentation • To generate reports which will include the main characteristic, parameters of teaching activity, the segmentation of the students, and the level of competence acquisition • To modify PDR and CDR of the devices and their documentation
5	Diffusion and VET competences network creation	<ul style="list-style-type: none"> • Creating of transnational network for monitoring and improving competences in engineering • Dissemination of project outputs, increasing the number of females in STEM • Creation of HE network for monitoring and improving competences in engineering

The main idea of this project is to establish a collaborative network among the partners to support the interconnection of university systems and education, to develop innovative teaching methods, and to promote STEM/STEAM development in higher education, reward excellence in learning, teaching, and skills development, and create inclusive university systems. The goal is to stimulate competition by updating the digital skills of people directly and indirectly involved in the project, with a particular focus on female participation. The target groups of the project are professors, students, and professionals.

The project addresses activities in the following areas: international cooperation between higher education institutions (HEIs) and other competence bodies, such as enterprises, colleges, and research institutes, to accelerate innovation and knowledge transfer; training for vocational education and training (VET) teachers organised in close collaboration with stakeholders across EU countries. The introduction of digital sharing and remote access for VET training in mechatronics technology will facilitate the establishment of a global VET knowledge repository, which can be shared with and contributed to by a wider group of participants.

Among the clear objectives is the creation of a digital network to make best practices of HEI professors accessible and standardised. The project also aims to support the interconnection of university systems, develop innovative teaching methods, promote STEM/STEAM development in higher education, reward excellence in learning, teaching, and skills development, create inclusive university systems, and support the development of digital skills.

1. MECHATRONICS IN SECURITY ENGINEERING

Mechatronics is a powerful enabler in handling and preventing crises, as well as in ensuring safety and security in a rapidly evolving world. Knowledge in mechatronics contributes to life-saving technologies, the building of resilient systems, and intelligent responses to emergencies.

Knowledge and competences in mechatronics for security engineers are fundamental and can be applied in various areas:

- (i) Disaster Response and Management: Robotic systems (e.g., drones, search-and-rescue robots) can access hazardous or collapsed areas after earthquakes, floods, or fires; autonomous systems can deliver aid or assess damage without risking human lives (Karluklu et al., 2025).
- (ii) National and Cyber Security: Mechatronic systems are essential in surveillance, defence drones, and automated border control, cyber-physical systems must be secured from hacking, making mechatronics a frontline in cybersecurity defence.
- (iii) Critical Infrastructure Protection: Many critical systems (power grids, water supply, transportation) use mechatronic control systems (SCADA - Supervisory Control and Data Acquisition, PLCs - Programmable Logic Controllers), as reported in (Rea, P., 2025a), (Rea, P., 2025b), (Rea, P., 2025c). A failure or attack on these systems can cause national-level crises. Security engineers help design, monitor, and secure such critical infrastructure elements (Ottaviano, E., 2023), (Rea, P; 2024).
- (iv) Pandemic and Health Crisis Response: Automation and robotics in medical equipment, telemedicine, and disinfection robots are powered by mechatronics. Mechatronics enabled fast development and deployment of ventilators and automated testing devices during COVID-19.
- (v) Environmental Monitoring and Climate Crisis: Mechatronic systems such as sensor networks, satellites, and autonomous underwater vehicles help monitor pollution, deforestation, and climate change and can help prevent or mitigate ecological disasters by early detection.

2. IDENTIFICATION OF ENGINEERING COMPETENCES

One of the aims of the project is to design a certification scheme for students to enhance the digital skills of people directly and indirectly involved in higher education and training, with a particular focus on female participation, following a digital approach under the framework of the MISCE project.

An essential part of the project is to identify the technical competencies in engineering degrees that require improvement at different levels or locations. To achieve this goal, the process involves not only higher education teachers but also students and professionals from specific sectors. The theoretical acquisition of technical competencies by students will be mandatorily contrasted with the assessments of professionals to provide a more realistic validation.

Following the identification of competencies, validation of non-formal and informal competencies plays an important role in promoting lifelong learning, enhancing social inclusion, and boosting employability. This process allows individuals to identify, document, assess, and certify the full range of abilities, competencies, and knowledge acquired throughout life, whether gained from non-formal or informal settings, or through work experience. From the perspective of the European regulatory context, the Council Recommendation (2012) provides important guidance for EU Member States to promote and facilitate the validation of non-formal and informal learning.

For the recognition of skills and the validation and certification of acquired competencies, the Digital Competence Framework (DigComp, 2025) is determinative. The Digital Competence Framework for Educators (DigCompEdu) is a scientifically sound framework describing what it means for educators to be digitally competent. It provides a general reference framework to support the development of educator-specific digital competences in Europe. DigCompEdu is directed towards educators at all levels, from early childhood to higher and adult education, including general and vocational education and training, special needs education, and non-formal learning contexts.

Validation of competencies will be conducted on the ICEP dedicated certification platform (ICEP, 2025), with individuals receiving certification through the European digital certificate.

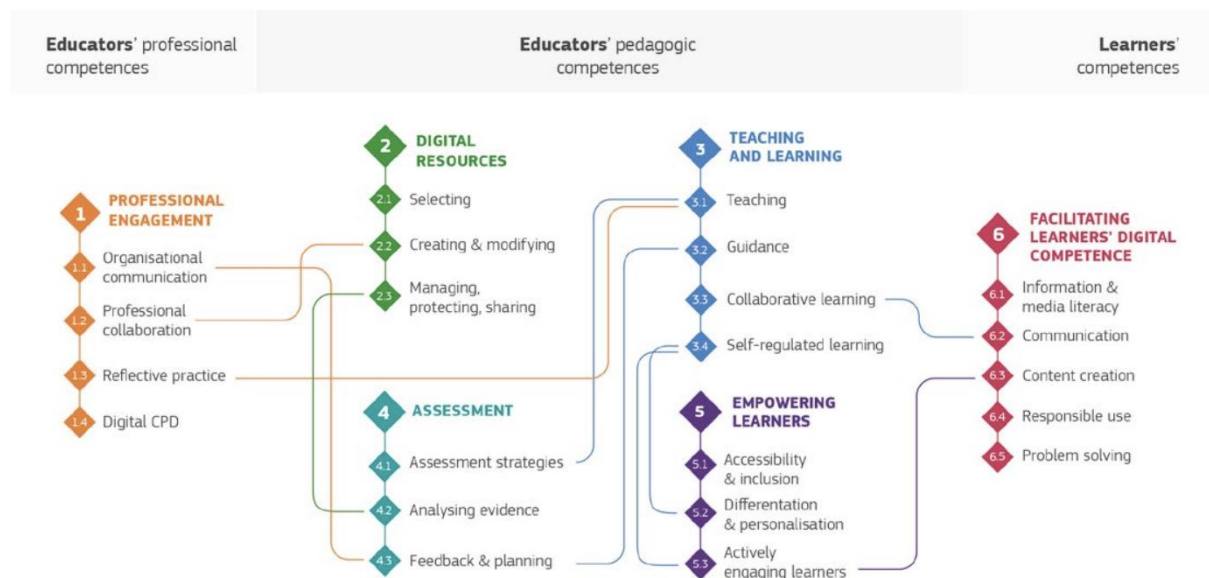


Figure 1 Digital Competence Framework (DigCompEdu, 2017)

During the development of the project, the competences were identified with a focus on mechatronics, related to the ESCO framework. ESCO (European Skills, Competences, Qualifications and Occupations) is a multilingual classification system developed by the European Commission to standardise and harmonise the description of skills, competences, occupations, and qualifications within the European Union. It serves as a common language to facilitate communication and collaboration between different stakeholders in the labour market and education sectors. ESCO defines competences as the ability of an individual to apply knowledge, skills, and personal, social, and methodological abilities in work or study situations. Competences are broader than skills and refer to the capacity to use knowledge and skills in a flexible and adaptable way, particularly in new and unforeseen situations. ESCO competences are categorised within the skills pillar of the classification.

During the project, in Work Package No. 2 – Identification of Engineering Competences – the technical competencies of engineering degrees requiring improvement at different levels or locations were identified. A total of 16 competences were selected (see Table 2).

Table 2 Identified ESCO competences with the project MISCE

1	Control engineering	Understanding the static and dynamic responses of a system
		Proficiency in implementing/utilising PID-type controllers
		Tuning various controller parameters
		Identifying unknown systems
		Enhancing the dynamic responses of controlled systems
2	working with machinery and specialised equipment,	To identify the main functional components of equipment
		To understand the functional behaviour of the machinery and equipments
		To design/modify different components of the system
		To know the security rules of the machinery
		To apply the proper maintenance of the machinery
3	using precision instrumentation and equipment	To know the main parameters of the measurement instruments
		To know how to configure/setup the instruments
		To know how to calibrate the equipment
		To maintain the precision instrumentation and equipment
		To be able to interpret the obtained measurement
4	management skills	To manage the human resources communication
		To schedule the time planning of the production and the budget planning
		To ensure a proper communication channel between different roles
		To coordinate the available resources
		To manage the conflicts and solve the problems
5	mechanical design	To know the main mechanical element of a device
		To be able to solve and understand the kinematics and dynamics behaviour
		To know the material properties of the different functional element of the machine
		To know how to integrate the mechanical parts with other main system
		To design/modify different components of the system
6	automation technology	To know the main electric/pneumatic and hydraulics elements
		To be able to design the functional behaviour of the system
		To be able to understand the technical documentation of a project/product
		To program the functional behaviour of the device
		To debug the final planned behaviour of the system
7	robotics	To know the different robotic architectures and their main features/applications
		To understand the main parameters of a robotic system
		To understand the inverse kinematic and robot trajectories
		To be able to programme the robot's behaviour
		To know security rules to a safety operation
8	material mechanics	To know the main mechanical properties of the materials
		To know the correct application of materials
		To know the procedures to analyse the material properties
		To know the different manufacturing and surface treatment techniques
		To know the response of the materials to different static, dynamic and cycling loads
9	computer engineering	To know the main parameters of current computer architectures
		To be able to characterise and evaluate computer performance for a given application

		To understand optimisation techniques of current computer architectures
		To understand the implications of application binary interface in software development
		To understand communication issues in computer architectures
10	computer programming	To be able to use proper data structures
		To be able to develop programmes to solve engineering problems
		To be able to characterise the performance of programmes
		To be able to debug faulty programs
		To be able to optimise programmes
11	mechatronics	To develop an integral design of a mechatronic device
		To design the mechanical and electromechanical parts of the device
		To integrate and programme the system behaviour
		To design the calibration/maintenance procedures of the device
		To validate the final product/process
12	database and network design and administration	To develop an integral design of databases and networks
		To design databases and networks
		To know how to ensure the security of databases and networks
		To know how to protect the critical data
		To validate the final databases and network architecture
13	programmable logic controller	To know the basics architecture of PLC
		To know how to manage Digital IO
		To know how to manage Analog IO
		To know how to implement the complete functional behaviour of a system
		To integrate PLC into an industrial network
14	mechanical systems	To understand the different energy conversion process to produce movement
		To know to design a mechanical system
		To know the different movement transmissions
		To be able to analyse and optimise a mechanical device
		To know the force and torque involved in mechanical systems
15	set up machine controls	To know the main security rules involved in the machine installation
		To ensure the proper installation process of the machinery
		To know the main functional components of the machine
		To understand the supply requirements for the machine setup
		To be able to modify the machinery setup
16	CAD software	To properly select the CAD software according to their main features and the project requirements
		To be able to interpret technical drawings
		To have the basic knowledge necessary to recreate the geometry of machine elements and its modification
		To know how to efficiently use the CAD programme to create parametric 2D and 3D technical drawings
		To know how to use CAD systems to design a simple device or mechatronic system according to the given specifications

During Work Package No. 4 – Competences Monitoring and Reengineering – selected competences were reengineered, and the final twelve main ESCO domains were established, with five sub-competences/practical skills selected for each. From the previously identified competencies, five were removed: (3) Using precision instrumentation and equipment, (4) Management skills, (8) Material mechanics, (9) Computer engineering, and (15) Setting up machine controls. One competence was modified: instead of *Mechanical Design*, *Mechanical Engineering* was considered. Additionally, one competence was added – *Wind Energy* – with five sub-competences: understanding different turbine designs, engineering and designing turbine components and systems, practical skills in setting up onshore turbines, ongoing maintenance of wind farms, and assessing the suitability of wind farm sites.

3. DEVELOPMENT OF TEACHING MATERIAL AND DIGITAL REPOSITORY

3.1. Teaching Material

The main requirements for designing the teaching material for each technical competence are as follows:

- It shall clearly contribute to the development of the skills associated with each competence.
- The materials for building the designed platform shall be accessible and inexpensive relative to the device’s performance.
- The software for managing the devices shall allow easy operation of the device.
- Each competence/device shall include the corresponding documentation: Preliminary Design Review, Critical Design Review, Mounting Instructions, Software, and Teaching Material for both professors and students.

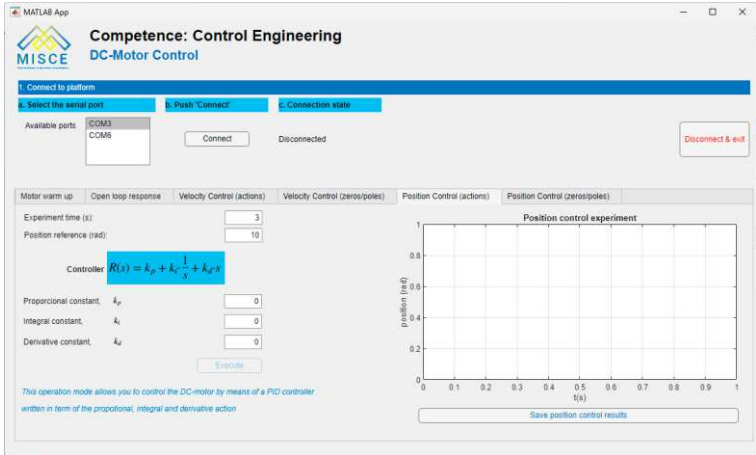
As an illustrative example, Figure 2 shows the design of the experimental platform developed, the actual device, and the software created to manage it for the *Control Engineering* competence.



a) Design of the DC motor control platform



b) Final aspect



c) Developed software to manage the 'DC motor control' platform

Figure 2 Control Engineering competence: 'DC motor control' platform

3.2. Digital Repository

A standard file format has been established for organising the documentation of each device or virtual platform, which contributes to achieving the expected level of competence acquisition. In this way, the structure of each folder contains several subfolders with information summarised in Table 3. These folders have been hosted on Dropbox.

The online repository of teaching material was initially built as a fully static AstroJS/Starlight application, stored in a private GitHub repository (uclm-mantis/misc) and synchronised with the aforementioned Dropbox folder. However, it grew rapidly, prompting a reconsideration of the architecture as the GitHub repository size limits were being approached.

Table 3 Content of the subfolder's repository for each competence

Folder	Content
Preliminary Design Review	This document contains the analysis of the competence and their skills, the different proposals and their contribution to the competence/skills.
Critical Design Review	This document contains the detailed design of the device/virtual platform developed by the competence workgroup.
Mounting Instruction	It provides the detailed instructions to mount/install the device/virtual platform developed by the workgroup.
Software	This folder contains the software required or developed to manage the device/virtual platform.
Teaching Material	According to the device/virtual platform developed, it contains the teaching material for both, professors and students.
Teaching Activities and KPIs	This is a brief document which describes the teaching activities developed during the project and the contribution to the different Key Performance Indicator.
Questionnaire	This folder contains the satisfaction questionnaire that the student completed and a summary of the result.

Today, the system is built as a cooperation of three different repositories: uclm-mantis/misc-dropbox mirrors data from the main shared Dropbox folder once a day; an auxiliary repository, uclm-mantis/misc-docs, automatically filters data from the Dropbox mirror, adds licensing statements to PDF documents, and exposes documents through a private web interface; and a third repository, uclm-mantis/misc, provides an AstroJS/Starlight frontend implementing several views of the available data. In the near future, uclm-mantis/misc will provide direct access to all the results of the MISCE project, including assessment data, through the URL: <https://uclm-mantis.github.io/misc/>.

This repository design is flexible and easily scalable. To add a new competence, device, or virtual platform to the digital repository, the user only needs to upload the corresponding documents to the Dropbox folder, following the structure shown in Table 3. Every day, at 03:00 a.m., the MISCE repository automatically updates its content with the information found in the Dropbox folder. For illustrative purposes, the final structure of the digital repository is shown in Figure 3.

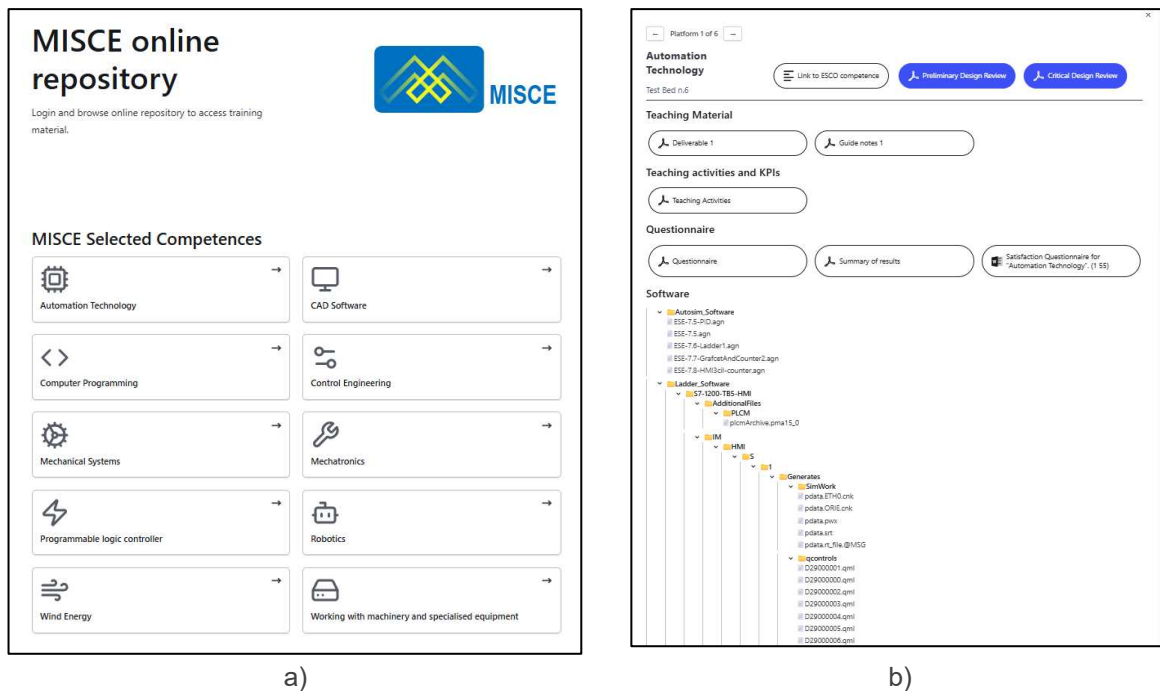


Figure 3 Final aspect of the digital repository. a) Main view; b) Competence view (automation technology)

CONCLUSION

The MISCE project represents a significant step forward in the identification, development, and validation of technical competences essential for engineering education, with a strong focus on security-related challenges. By adopting mechatronics as a unifying framework, the project effectively bridges academic training and industry demands, fostering a modern, multidisciplinary approach to engineering education. Through the collaborative efforts of universities and institutions across Europe, the project has defined a standardised set of engineering competences aligned with ESCO guidelines and supported by robust teaching materials and digital infrastructure. The creation of physical and virtual training platforms, along with an open-access repository, enhances accessibility and fosters innovation in higher education. Moreover, the project contributes to the advancement of digital skills, the inclusion of underrepresented groups in STEM, and the promotion of lifelong learning through certification mechanisms recognising informal and non-formal learning. The integration of these strategies into security engineering ensures that future professionals are better prepared to address societal challenges, including crisis management, critical infrastructure protection, and environmental monitoring.

A transversal dimension that emerged during the project is the role of **artificial intelligence (AI)** in the development of **cyber-physical systems (CPS)**. While AI is explicitly recognised as a competence in the ESCO framework, MISCE has chosen a different strategy: rather than treating AI as an isolated competence, it has been **embedded into other domain-specific competences** such as control engineering, robotics, automation, network security, and database management. This reflects the reality that AI increasingly permeates all areas of engineering practice and acts both as a catalyst for innovation and as a potential source of risk.

By adopting this integrated approach, MISCE highlights AI's dual role. On the opportunity side, AI supports predictive maintenance, real-time risk detection, autonomous decision-making, and adaptive responses to crises, thereby strengthening CPS resilience. On the threat side, AI-driven systems are vulnerable to adversarial manipulation, biased or opaque decision processes, and cascading failures if compromised. Embedding AI considerations across competences ensures that engineers not only master the enabling technologies but also remain critically aware of the vulnerabilities and ethical implications linked to their use.

Overall, MISCE offers a replicable and scalable model for competence development in engineering, reinforcing the relevance of mechatronics in education and its impact on security, sustainability, and innovation in Europe.

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