

***DIGITIZING PRODUCTS:  
CREATING DEMONSTRATORS  
FOR FUTURE EDUCATION***

**digi  
demo**

# **Mechatronics and IoT: Literature and study programme analysis**

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**Fagskolen**  
i Viken



**FH Vorarlberg**  
University of Applied Sciences



**ésta**  
school of business & technology  
Belfort

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### About the DigiDemo project

Environmental challenges and digital transformation are two of the main drivers changing the world and the way business will be done in the future. Therefore, it is essential to enable future employees to address these drivers. The skills and competences needed to develop digitalized products and awareness of the environmental challenges are therefore crucial for the European workforce and industry to continue being competitive in a future green economy and to maintain jobs across Europe.

The DigiDemo project addresses these challenges by developing demonstrators especially for higher education allowing to improve mainly mechanical engineering studies by integrating skills and competences allowing them to understand, develop and commercialise connected products. The results will be publicly available and can be used by every institution interested in integrating this type of training in their cursus.

<http://www.digidemo-project.eu>



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## Document authors

	First name Last name	Institution
<b>Key author</b>	Julien Gaudry / Sylvain Sagot / Thomas Röhr	ESTA
<b>Further authors</b>	Esben Laursen	UCN
	Horatiu Pilsan	FHV

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## Abbreviations

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CAD	Computer Aided Design
ESTA	ESTA Belfort (France)
FHV	Fachhochschule Vorarlberg (Austria)
FSV	Fagskolen I Vinius (Norway)
HEI	Higher Education Institution
ICT	Information and Communication Technology
IoT	Internet of Things
Misc	Miscellaneous
OS	Operation System
SI	Significance indicator
SME	Small and Medium Enterprises
UBB	Centrul Universitat UBB din Resita (Romania)
UCN	University College Nordjylland (Danmark)

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## 1 Introduction

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### 1.1 Project schedule

The need of mechatronics/IoT in the industry is very important; companies need specialized engineers who understand all features of an intelligent and connected product.

DigiDemo is a European Union project, co-funded by the Erasmus+ programme of the European Union, initiated to develop and improve mechatronic teaching in Higher Education Institutions (HEI). DigiDemo's goal is to design teaching demonstrators to convey and to improve mechatronic skills for students. These demonstrators can be easily included in mechatronics lectures to complete existing curricula.

In a survey of potential employers in Texas, 63 % agreed with the idea job competences in mechatronics had to be acquired through on-the-job training. And 80% agreed with the fact that that formal mechatronic training would decrease the time necessary to gain the skills required for mechatronic employment and thus minimise the risk of hiring a person not fulfilling expectancies (Mishra et al., 2011). The result of this survey highlights that: (1) train mechatronic engineers / technicians is useful for the industry to reduce the time to form a new employee. And (2), there is a need to design and use demonstrators as useful tool to simulate "on-the-job training" and to learn mechatronics.

Firstly, we investigated existing literature to determine the competences that is and must be taught in mechatronics education. As products become more and more connected, the educational field of Internet of Things (IoT) has been added to the literature analysis. Both analyses allowed the identification of additional competences for future mechatronics engineers at the swell between both study domains and to propose an enhanced model based on the mechatronics scheme described by Brown and Brown (2002).

Secondly, search about mechatronic programmes in European HEI has been conducted, and results have been compared with findings from the literature review and especially the enhanced model for mechatronic studies. For that, a survey addressed to all DigiDemo project partners served to gather complete lists of lectures of mechatronic study programmes as basis for the subsequent analysis. The analysis of the survey data allowed the determination of skills and knowledges that should be acquired by mechatronic students.

Thirdly a benchmark of the competences taught in the existing study programmes at the DigiDemo partner HEI has been conducted to define a level of accordance of these programmes with mechatronic study requirements. This benchmark enables the DigiDemo partners to design improved study curricula by adding missing competences. DigiDemo demonstrators shall help the partners in this way.

## 2 Definition of mechatronics and IoT

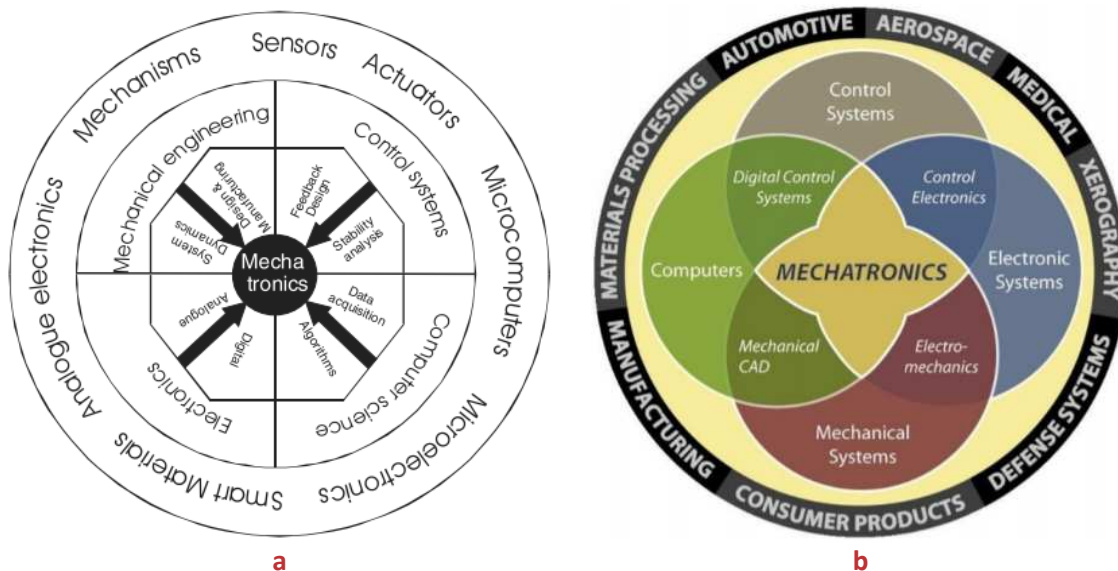
### 2.1 Mechatronic definition and scheme

The term 'mechatronics' is generally attributed to Tetsuro Mori who first mentioned this name in 1969 to describe the integration of electronics with mechanical engineering (Bradley, 2010; Escobar Carvajal et al., 2019; Mishra et al., 2011). Since this date, mechatronic is evolving to adopting new technologies.

Figure 1a describes a mechatronic scheme regrouping the different elements and engineering sciences required for a mechatronic system (Brown & Brown, 2002). Thus, a mechatronic system is a smart system based on multiple sciences to be autonomous. Intelligence is embedded in the product. The best example for a mechatronic system is the robot with multiples sensors, actuators, electronic components and software for remote control and other functions.

It's important to say that mechatronic is homogeneous; for example learn mechanic, electronic and computer science independently isn't a mechatronic approach, mechatronic is based on different sciences but with the interaction between these sciences as presented by Peña et al. (2012).

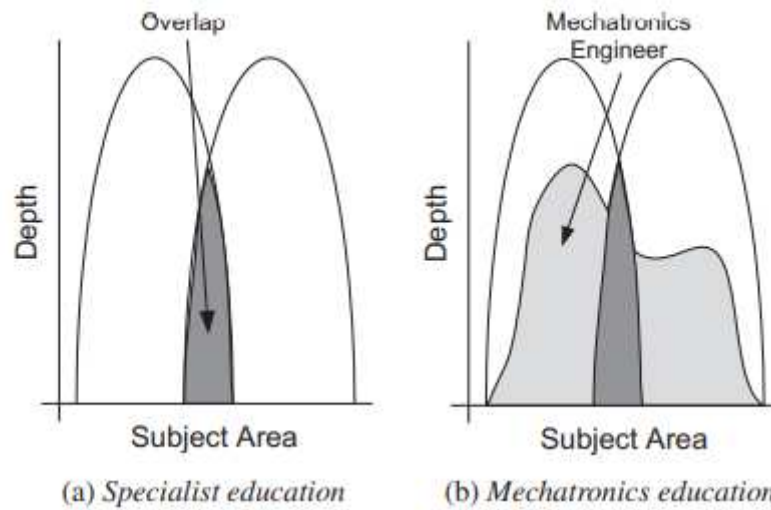
In the same register but later, Figure 1b describes a similar vision of mechatronics as a transdisciplinary science. The scheme by Vaccaro et al. (2016) shows the same four basic elements, control systems, computer science, electronics and mechanical engineering, but highlights in addition the overlapping areas between the different elements.



**Figure 1** Mechatronic system scheme by Brown & Brown (2002) (a) and a model-based design of mechatronics systems (Vaccaro et al., 2016) (b)

But what is their profile? Bradley (2010) proposed that mechatronics engineers does not necessarily must have a depth of knowledge in specific areas, but that the lack of depth is

balanced by an understanding and appreciation of the contributions of other areas of technology as it's suggested by Figure 2.



**Figure 2** Balance of technical expertise for specialist and mechatronics educated engineers. (a) Specialist education, and (b) mechatronics education (Bradley, 2010)

Mechatronics continues actually integrating new domains as e.g. the implementation of IoT in mechatronic system (Stark et al., 2020) with the use of augmented reality and IoT devices for the maintenance of mechatronic systems.

## 2.2 IoT definition and scheme

The Internet of Things (IoT) is a network of connected/virtualised physical objects “things” or places. The goal of an IoT object is to collect data or receive data from the Internet. Thus, intelligence for IoT devices is centralised in distant systems in the cloud.

Smart devices can be a both mechatronic and IoT objects. In fact, mechatronics devices are getting more and more connected via the Internet and joining the IoT, often for reasons and functionalities such as maintenance, reducing costs, added value services etc. The difference lays in the remaining intelligence in mechatronic systems that can continue functioning, perhaps in a limited way, when the connectivity is disturbed.

The intelligence of the IoT device is in the cloud; therefore, IoT specifications can be interesting in the design mechatronics systems: If a part of the intelligence is relocated to distant servers in the cloud and if the product is connected to Internet, the design can be simplified with a minimum of electronic components. This will result in less costs (for embedded systems), simplification of the product design, and perhaps energy saving (without calculators for example). Figure 3 shows the different fields and sciences for IoT systems in the same philosophy as the one from the Figure 1.

Figure 3 is based on 4 European IoT curricula (ISEP France, ECE France, University of Southampton United Kingdom, Universidad complutense Madrid Spain) and visualises the different domains and sciences behind an IoT system.

IoT skills and knowledge fields

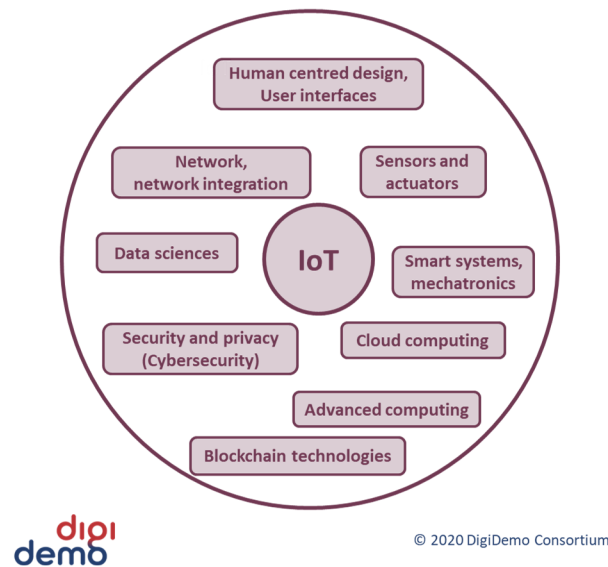


Figure 3 IoT skills and knowledge fields' scheme (own figure)

The different skills and knowledge fields are:

- ❖ **Data sciences:** data sciences are necessary to IoT projects because the core of the Internet of things is to collect data and use data.
- ❖ **Blockchain technologies:** blockchain technologies are very important for IoT due to the huge amount of data. *“Thus, the secure, scalable, and efficient management of resources may well be one of the most important objectives for the realization of the future IoT network. A distributed peer-to-peer decentralized cloud storage solution is required to achieve the objectives for the future IoT network. Recently, blockchains have recently attracted the attention of researchers in a wide range of industries”* (Sharma et al., 2018).
- ❖ **Security and privacy:** use and collection of data are precious; in this way the cybersecurity is important to protect data of the IoT device.
- ❖ **Cloud computing,** the cloud computing is a science necessary to IoT projects, huge data amounts are collected by smart devices need to be treated and stored (big data).
- ❖ **Network and Network integration** are the link between the physical products and the virtual universe of IoT.
- ❖ **Human centred design and user interface:** this part of IoT establishes the interface between the user and the smart device, it can be e.g. a touch screen, a voice assistant, or a virtual reality control as explained by Stark et al. (2020).
- ❖ **Sensors and actuators:** these are core components of an IoT device to collect data. And transform commands into actions.
- ❖ **Smart systems or mechatronics:** smart systems are a component of many IoT devices, and this part establish the link between IoT network and mechatronics systems.
- ❖ **Advanced computing:** IoT project needs high capacities in computer sciences and specific competences to handle and analyse huge amounts of data.

A survey by Assante et al. (2018) with 800 participants from different companies and countries, of which 41% were from the target group SMEs and further analysed. The survey results highlight the main IoT training needs required by companies. The results are important information when designing demonstrators for mechatronic students with enhanced IoT skills and knowledge.

**Table 1: Training needs for IoT engineers in different domains of IoT (n=800)  
(Assante, Romano, Flamini, Migliori, et al., 2018)**

Domain	Training need	Mentioning
<b>Hardware</b>	Sensors	29%
	Microcontrollers	23%
	Designing circuit	18%
	Microprocessor	12%
	Signal processing	12%
	System on chip	6%
<b>Mobile computing</b>	Android development	35%
	Mobile application design/experiences	27%
	OS development	19%
	Multiplatform development	11%
	Universal windows platform development	8%
<b>OS and Embedded systems</b>	Overview of embedded development and OS	31%
	Application development for embedded systems	29%
	Framework for embedded development	17%
	General Kernel programming (Linux)	11%
	Process/thread and scheduling	9%
	Driver Development	3%
<b>Distributed architecture</b>	Middleware for IoT	48%
	Introduction to Client/Server application	15%
	Web services architecture	15%
	Data collecting in the cloud	15%
	Parallel programming	7%
<b>Communication, Networks and Protocols</b>	Low power, short range wireless protocols	27%
	Low power, long range wireless protocols	27%
	Introduction to networking	23%
	Web protocols	20%
	Time constraints protocols	3%
<b>Expected advantages to leveraging the IoT according to ICT staff</b>	Data analytics and services	28%
	Customer services and engagement	26%
	Asset tracking and monitoring	18%
	Improved workflow and processes	16%
	Automated manual processes	12%

## 2.3 Link between IoT and mechatronics

### 2.3.1 IoT and mechatronics in Industry 4.0.

Digitalisation of companies has a direct impact on the design of mechatronic projects. For example, Stark et al. (2020) present a new application combining IoT and augmented reality to design the best user interface for the maintenance of mechatronics systems such as digitalized factories with robots. Bordin et al. (2020) explain how to practise energy management thanks to IoT data using the example of new houses. The household appliances are still mechatronic devices, the goal is to design modern household appliances connected to the IoT as part of the connected house. Data will be useful to manage energy, and, on a big scale, allow adapting the production of energy. Penas et al., (2017) warn about problems that can arise between different domains when communication is missing during the design process connected mechatronic systems due to their complexity. Metwly et al. (2020) present the use of IoT for a big mechatronic system: an electric car. The paper treats about the use of IoT to manage a new vehicle recharging system. Coronado & Venture (2020) describe a human-robot and robot-robot interaction using of IoT. In the same field, Kokovin (2020) presents a distributed control system to allow different mechatronic devices to interact between each other and with isolated sensors or actuators. In these examples we saw the new field of engineering; the interactions between IoT and mechatronics systems for better human/robot interfaces, energy management, and factory management for maintenance.

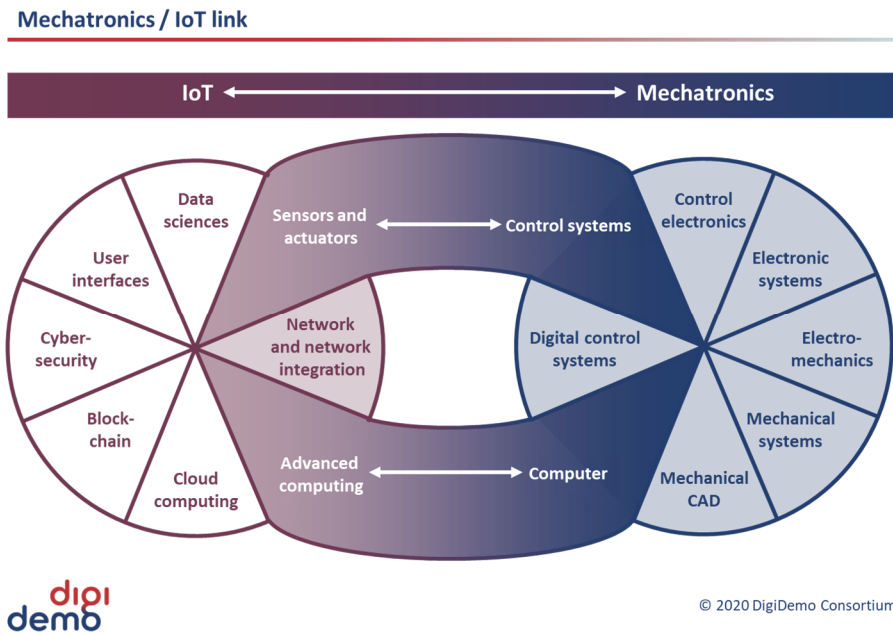
### 2.3.2 Links between IoT and mechatronics in education

The link between IoT and mechatronics is increasingly present in industry thanks to the advantages that this association brings. Nevertheless, development and use of connected mechatronic systems are slowed down by a lack of qualification of engineers especially regarding connectivity of products. Eichinger et al. (2017) identified a lack of interest in digitalisation from mechatronic students. Even though this is something that is already disrupting mechatronics, the authors suggest solutions with more industry-related projects to motivate students. Krauss (2016) presented a demonstrator for mechatronic students using both Arduino and Raspberry Pi microcontrollers. This association allowed building a connected demonstrator. Carlos-Mancilla et al. (2020) describe a connected weather station demonstrator measuring eight parameters and transferring them to a cloud computer.

The growing number of publications highlights the need and willingness to complete mechatronic studies with additional digitisation competencies.

The DigiDemo project aims at creating demonstrators for mechatronic education, and it is essential to know which IoT domains should also be integrated into the demonstrators. In any case, as products will get more and more connected, mechatronic engineers will also need knowledge and skills enabling them to consider connectivity aspects or data exchanges with and from distant systems.

An evaluation of both IoT and mechatronics schemes shows similarities in three fields: Sensors and actuators and control systems, advanced computing, and computer, and finally IoT and mechatronic systems combining several or all fields of their domain (Figure 4). In addition to these overlapping skills and knowledge fields, the network and network integration field of IoT seems also interesting to be included in mechatronic education.



**Figure 4 Links between IoT and mechatronic (based on Vaccaro et al. (2016) and own investigations)**

The DigiDemo demonstrator framework thus includes a parameter allowing defining whether the demonstrator includes and enables learning of mechatronic elements, IoT elements or elements from both sectors.

### 3 Mechatronics education and demonstrators

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#### 3.1 Demonstrators

The demonstrators are learning tools that improve students' specialized skills. Demonstrators can be robots, simple mechanical parts, or virtual simulations. For example, build an autonomous robot to improve engineering, electronics, and programming skills. DigiDemo's demonstrators will be classified by their property (what kind of skills they improve, what knowledge is necessary to solve the problem, the safety level...). Some demonstrators can be realized by students, but others can be used for demonstration effects. The different characteristics of demonstrators are described in DigiDemo's dedicated "Framework for Demonstrators" document.

#### 3.2 Learning methods for demonstrators

In this part different learning methods are briefly described that are used in mechatronic curricula and can be associated to demonstrators.

##### Classic lecture

This is the "classic learning method". The lecturer explains a concept to students, it can be interactive or not. Demonstrators can be a support for the teacher to explain concepts or functioning. For example, a little gearbox with transparent structure can be useful to explain the different part of it (Castles et al., 2010).

##### Guest lecture

The Guest lecture is a learning method appreciated by students because they can establish a link between the course and the industry (Castles et al., 2010).

##### Self-learning

The self-learning is popular in mechatronics studies due to the practical aspect of the mechatronics, students need to learn themselves to allow the teacher to help them on projects (Nieh & Chou, 2018; Phan & Ngo, 2020) particularly when students needs to solve a big problem or are working on engineering project. It is usually in pair with project-based learning.

##### Project based learning

The Project based learning is one of the most popular approaches in mechatronics studies because mechatronic is an experimental science where students learn easier the different sciences (mechanics, computer science, electronics...) by experiments and projects. This is also a great preparation to the industry (engineers works in teams to drive a project) (Berry et al., 2020; Nieh & Chou, 2018; Phan & Ngo, 2020). Students gain knowledge and skills by working for an extended period to drive a project or challenge for example. This method uses self-learning and by the way is addressed to skilled, experienced, and confident students. The riderless bicycle project presented in the study of Nieh & Chou (2018) is a good example of demonstrator, students will acquire analysis skills and other mechatronic skills.

### **The flipped classroom approaches**

The flipped classroom approach is a type of blended learning where students are first learning content at home and practice working through it in class. This method typically inverts the classic cycle of content acquisition and application. The demonstrator could be a little robot assembly to apply skills acquired at home (Phan & Ngo, 2020).

### **The game development model**

The serious game method is quite like project-based learning. Both learning methods use projects to push students solving a given problem by self-learning. The game development model approach also adds a challenging dimension that stimulates the students. Robot competitions are a common example for this ludic teaching (e.g. Akagi et al., 2015).

### **Computer-based interactive learning**

In computer-based classrooms, students and teacher have a computer; they use it to show presentations or to try a mechatronic system by themselves. By that students improve their skills earlier than in a classic course. This learning method is also compatible with the project based learning (Alemohammad & Shahini, 2010). Teachers can use simulation tools for problem solving exercises.

### **Computer-assisted classrooms**

Computer-assisted classrooms become the norm today. In this type of classroom, the teacher has a computer to show presentation, videos, or test with virtual simulation of a mechatronic system (Alemohammad & Shahini, 2010).

### **Model-based design**

A new curriculum strategy is proposed in which at least one course each semester reflects the concepts of model-based design. (Vaccaro et al., 2016) This learning method is designed for bachelor curriculum in mechatronics. The goals are to copy the design process of a product to educate students and to start with conceptual problems (easiest) to real problems to senior students (hardest). This method is adapted to improve different skills at the same time.

## **3.3 Demonstrators in the literature**

### **3.3.1 Robot with gearbox assembly and Motor driver circuit-assembly**

Castles et al. (2010) describe this demonstrator that was introduced after a guest lecture aiming at introducing students to mechatronics. Students (in pair) had a presentation file to help them assembling the robot. The work had to be done autonomously, a teacher was only in the classroom to help students in case of difficulties.

This exercise totals 3 steps:

#### **The gearbox assembly**

The gearbox assembly introduces students in mechanical engineering. They have access to all necessary parts thanks to a kit (Figure 5a) and a PowerPoint with the assembly details. If they have difficulties, the teacher can help them to unlock the situation. This part of the

demonstrator is focused on the mechanic part; the goal of the students is to assemble a functional gearbox (Figure 5b).

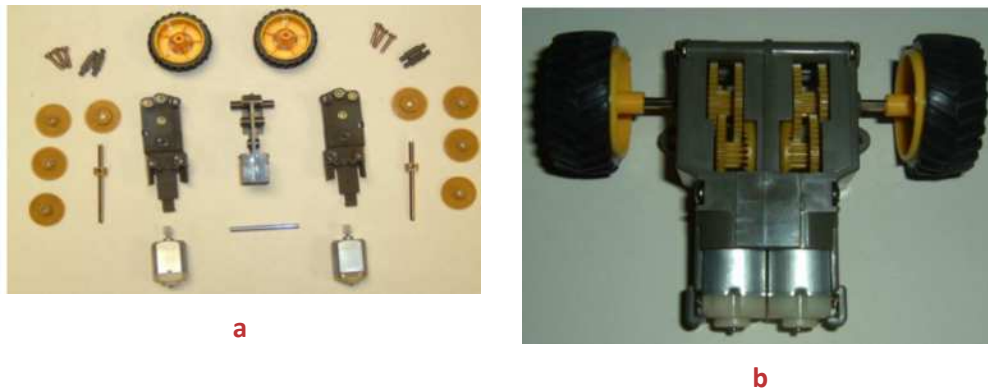


Figure 5 Parts of the gearbox (a) and assembled gearbox (b) (Castles et al., 2010)

### The motor driven circuit assembly

In this part, with the same learning scheme, students acquire electronic skills with the assembly of the motor driven circuit. They have the schema (Figure 6) to assemble it.

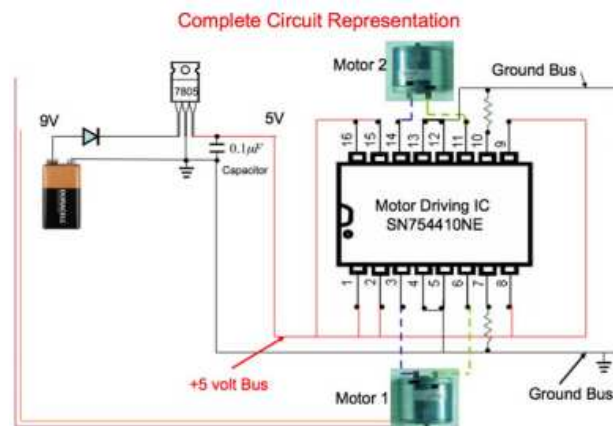
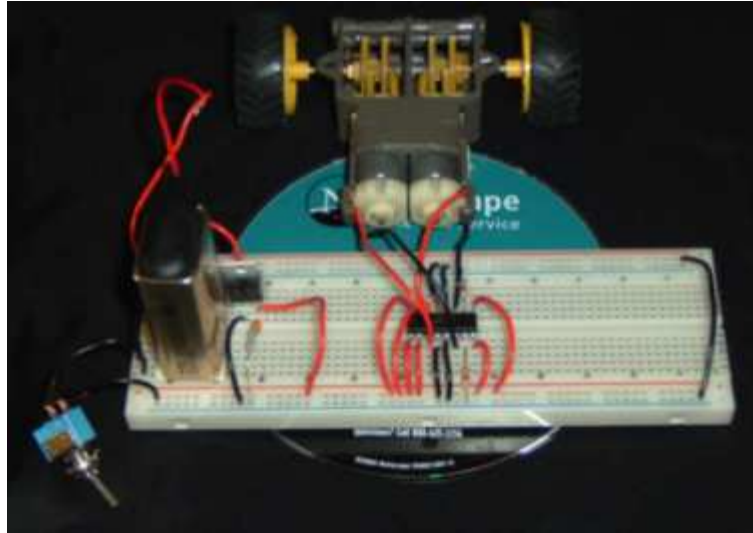


Figure 6 The complete circuit representation provided to the students (Castles et al., 2010)

### Final assembling of the robot

In this final part, students must finalise the robot. This part is the easiest and the shortest part of this demonstrator. Figure 7 shows the complete robot assembled by students.

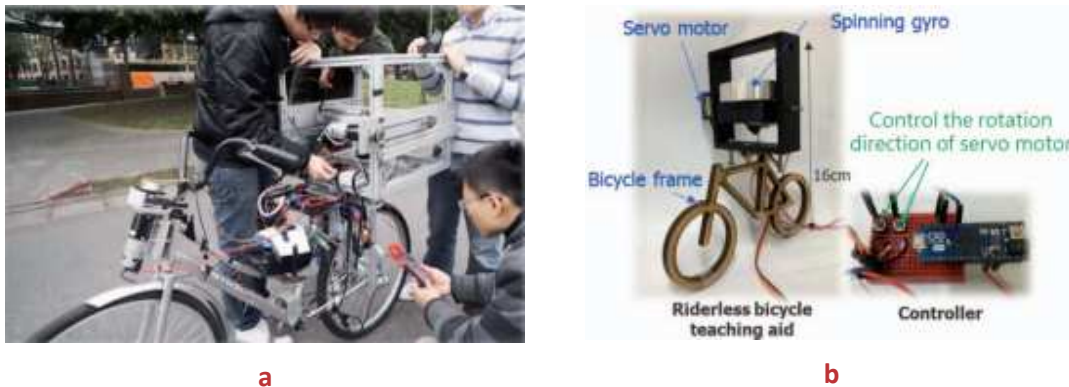


**Figure 7** The completely assembled robot (Castles et al., 2010)

Finally, students built in teams a functional robot. That improves their mechanical, electronic and teamwork skills as well as their capacity to drive a project.

### 3.3.2 Riderless bicycle

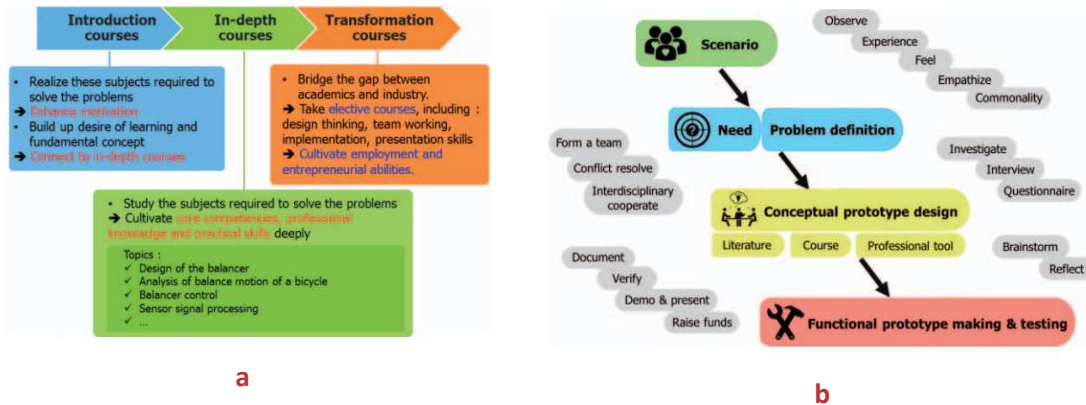
The riderless bicycle demonstrator is a good example of demonstrator designed to a project-based learning curriculum (Nieh & Chou, 2018). Figure 8 presents the complete riderless bicycle (a) and the riderless bicycle teaching aid to help students during the development of the project (b).



**Figure 8:** Riderless bicycle (a) and mini riderless bicycle demonstrator (b) (Nieh & Chou, 2018)

The goal of this project-based learning is to improve five core competencies of the students, namely critical thinking, problem-solving, communication and discussion, cooperation, and innovation abilities.

Another objective of the project-based learning is to show why students' need to learn various subjects like programming, dynamics, sensors... Figure 9 illustrates the riderless bicycle series of courses (a) and the modified project-based learning method used in this project (b).



**Figure 9 Riderless bicycle series of courses (a) and modified project-based learning method (b) (Nieh & Chou, 2018)**

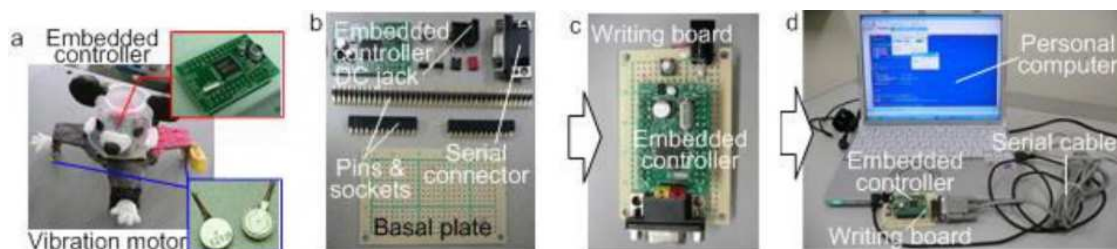
Finally, students will acquire by this project many mechatronic skills but also many soft skills useful to carry out a project.

### 3.3.3 Robot competition

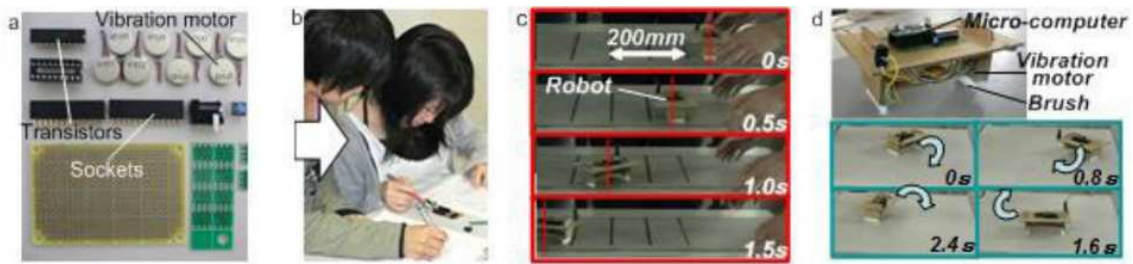
Robot competitions use the game development model to learn mechatronic skills to their students (e.g. Akagi et al., 2015; Grover et al., 2014; Yudin et al., 2019). The following demonstrator is adapted to each year of study (Akagi et al., 2015):

#### First year: Mobile robot competition using vibration motor for freshmen

To introduce new students in mechatronics, they must design and assemble a mobile robot (Figure 10). In a second step, students must design a controller for the robot (Figure 11).



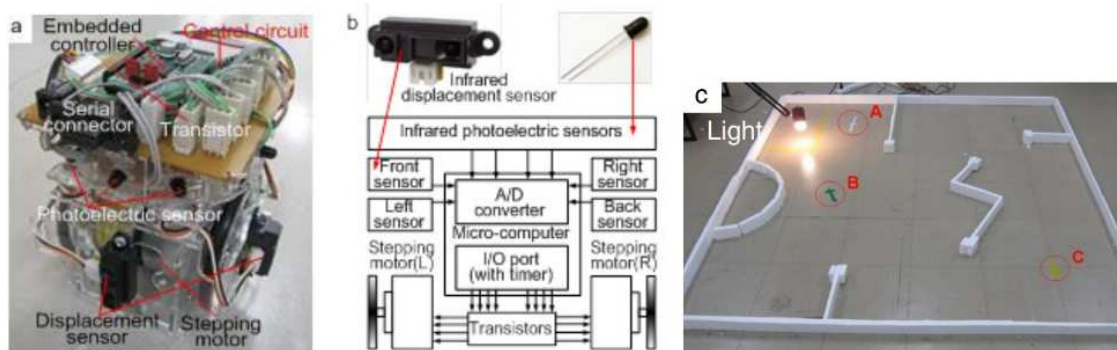
**Figure 10 Tested mobile robot; making process of writing board (a), electric parts (b), writing board (c) and setup for testing (d) (Akagi et al., 2015)**



**Figure 11** Making process of controller; (a) robot module parts (b) design of circuit; Robot competition (c) strait moving trial; (d) rotating signal (Akagi et al., 2015)

### Second year: Automatic Searching Robot Competition

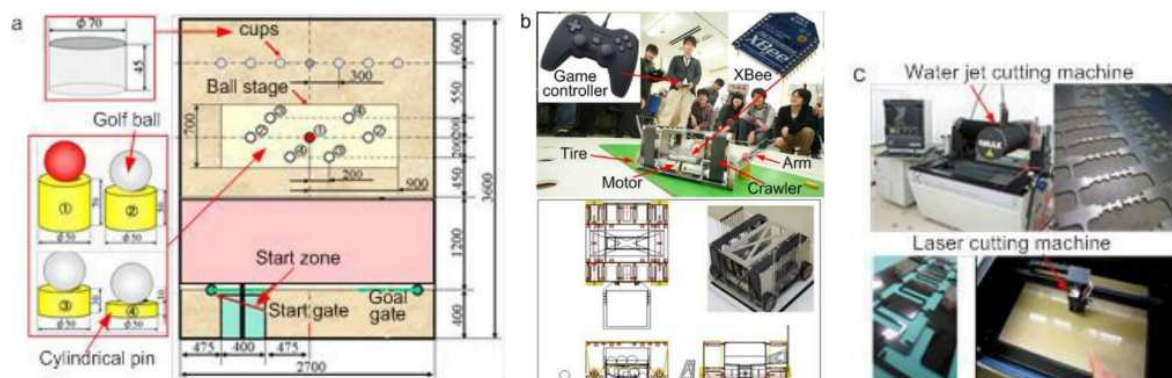
In the second year, students must develop an automatic searching robot with infrared displacement sensors, photoelectric sensors, an embedded controller, and a motor driving circuit. Figure 12 shows the automatic searching robot with its system diagram and the competition for the robots.



**Figure 12** Automatic searching robot (a), system diagram of the robot (b) and competition of automatic searching robot (c) (Akagi et al., 2015)

### Third year: Remote-controlled robot competition

Figure 13 shows the competition for the last year students' robots, the robots with different controllers and some manufacturing processes used by students to make their robots.



**Figure 13** Competition field of the hall toss game (a), remote-controlled robot (b) and water-jet and laser cutting machines (c) (Akagi et al., 2015)

So, for each year of study, students participate in robot competition adapted to their knowledge level in mechatronics. These competitions stimulate the creativity and the self-learning capacity of the students to win the competition.

### 3.3.4 Linking of demonstrators and learning methods

Table 2 resumes the different learning methods used in the three presented demonstrators.

**Table 2 Possible learning methods and acquired skills with some existing demonstrators.**

Author	Demonstrator	Guest lecture	Self-learning	Computer based learning	Flipped classroom	Project based learning	Game development model	Skills
(Castles et al., 2010)	Robot with gearbox assembly and Motor driver circuit-assembly	X	X	X	X			Mechanical system, electronics system, digital control systems, Mechatronics,
(Nieh & Chou, 2018)	Riderless bicycle	X	X	X		X		Digital control systems, electronic systems, electromechanics, mechanical systems, mechanical CAD, advanced computing, mechatronics, control systems.
(Akagi et al., 2015)	Robot competition	X	X	X		X	X	Digital control systems, electronic systems, electromechanics, mechanical systems, mechanical CAD, advanced computing, mechatronics, control systems.

## 3.4 Mechatronic curriculum requirement in the literature

This part highlights the choices of demonstrator requirements and skills necessary for mechatronic studies.

### 3.4.1 Requirements for mechatronic demonstrators

#### **Hardware for mechatronic demonstrators**

Hardware for mechatronic demonstrators need to respond to various criteria like price, the computer architecture, its durability, or the use in industry. In this way Giurgiutiu et al. (2005) said the 68HC11 (OTP microcontrollers) is a good choice. Furthermore, in their study, the authors selected two types of evaluation boards, one for code development (EVBplus2 microcontroller evaluation board from <http://www.evbplus.com/>), and the other for embedded applications (Adapt11C24DX microcontroller evaluation board from Technological Arts, Inc. <http://www.technologicalarts.com/myfiles/t1.html#EVBU>).

In another study Arduino controllers are used because they are priceless, small and powerful for mechatronic education (Chancharoen et al., 2014; Grover et al., 2014; Plaza et al., 2018). Raspberry pie is a good tool for mechatronic education too. Low-cost kits are provided, specifically for education, by the Raspberry Pi Foundation in conjunction with Google. These kits and modifications for optimal educational outcomes, and an enriched experience could be another good choice to design demonstrators (Valov & Valova, 2019; Yamanoor & Yamanoor, 2017). Another paper explains the use of raspberry pie and Arduino controller to design an autonomous vehicle. This association is interesting for connected mechatronic system (Krauss, 2016).

#### **Software for mechatronics**

Software for mechatronic education also need to respond to various criteria like usability in industry, adapted to mechatronics, strong compatibility with hardware selected, price.... The following list shows the software tools used in different publications:

- ❖ Dudziak & Kohn (2015) have selected the CDHA W in lecturing about production technology, programming language C++ and in supporting the mechatronics project.
- ❖ Nieh & Chou (2018) asked students to learn how to use professional platforms, for example, MATLAB, AutoCAD, and Arduino.
- ❖ Giurgiutiu et al. (2005) selected inexpensive microcontroller simulation software based on the assembly language THRSim11 by Harry Broeders.

#### **Interfacing of mechatronics**

The goals of interfacing are to be useful, simple for non-electric engineering students to improve their skills in mechatronics. The reason is: mechatronics engineers are various and specialized but they need knowledge in each field of mechatronics to drive a project (Giurgiutiu et al., 2005).

### 3.4.2 Other requirements for mechatronic studies

#### **Specialized engineers with a global view.**

Mechatronics are very complex and it's difficult to know what kind of an engineer the industry needs. One idea is to define mechatronic engineers as a specialized engineer with a high capacity to work in teams but also a specialized engineer with knowledge in the various areas of mechatronic to facilitate the communication between the different disciplines participating in a mechatronic project. This profile can be e.g. built with a specialized curriculum with a common core (system design, control..) (Oberhauser & Soriano, 2012).

### **Specialized generalist engineer**

Another view of mechatronic engineer is the "specialized generalist". With this approach the first part of the mechatronic studies are general (mechanical) engineering studies, e.g., on "bachelor level". After these general studies, the student chooses a mechatronic specialization, e.g. inform of a Master degree (Dudziak & Kohn, 2015; Oberhauser & Soriano, 2012).

### **Management and communication skills**

Due to the importance of teamwork in mechatronic projects and the responsibilities of engineers in research, they acquire skills in management and communication to improve their efficiency, to be able to do presentations of their work or to manage a team (team of technicians for example) (Nieh & Chou, 2018).

### **Analysis and synthesis skills**

Good analysis and synthesis skills are mandatory for mechatronic engineers and can help him in job. They help the engineer identifying problems, analysing them and designing a solution. The riderless bicycle demonstrator is an example for teaching this type of skills (Nieh & Chou, 2018).

### **Learning method: Problem; solution; self-learning; brainstorming; test; validation**

The "Learning method: Problem; solution; self-learning; brainstorming; test; validation." is a synthesis of what a mechatronics engineer needs to master. This method enables the engineer to work on different mechatronic projects (Nieh & Chou, 2018).

### **Project Management**

Project management is a requirement for mechatronic engineers, engineers will work on different project in the industry and the project management can help them drive these projects (Phan & Ngo, 2020)

## **3.5 Student evaluations of mechatronic demonstrators**

The goal of this part is to help designing demonstrators corresponding to requirement analysed in existing surveys.

Castles et al. (2010) asked 723 students about the difficulty of the "robot with gearbox assembly and Motor driver circuit-assembly" demonstrator, around 550 students said the building of the motor driver circuit (electronic part) was more challenging. In fact, students are in difficulty with the electronic part of the project. In the same study, students appreciated hands-on activities in their mechatronic curriculum.

Kolberg et al. (2003) asked their students about the mechatronic project-based course with four interesting points:

- ❖ First, students appreciated the course with the combination of thinking challenge and technological creativity.
- ❖ Second, students recognized the difference between classical science course and course of technology with more experiences to improve skills in teamwork and make them familiar with real design processes in engineering.
- ❖ Third, the necessity to understand the system behaviour and the need to complete the practical project on time motivated the students to learn theoretical subjects.

- ❖ And fourth, the contest oriented mechatronic project was seen efficient to increase the motivation of students and particularly non-technical students, thus preparing them to spend extra hours on the course.

Mishra et al. (2011) conducted a survey with potential Texan employers showing that more than 60 % agreed with the fact that hired engineers had to be trained on mechatronic issues once in their job, and 80% agreed with the fact that formal mechatronic training can help gaining time to make engineers operational in this domain, Table 3

**Table 3: Results of a survey conducted with potential Texan employers (Mishra et al., 2011)**

Most technicians hired in recent years have had to become mechatronic technicians, typically through on-the-job training, in order to maintain job competences	Strongly agree	17%
	Agree	46%
	No Opinion	26%
	Disagree	9%
	Strongly disagree	3%
Formal mechatronic training can materially decrease the time necessary to gain the skills required for successful mechatronics employment	Strongly agree	51%
	Agree	29%
	No Opinion	11%
	Disagree	3%
	Strongly disagree	6%

The survey results led to the following conclusions:

- ❖ Demonstrators are useful to motivate students to develop their knowledge in mechatronics with a link between university and professional experience (project structure quite similar).
- ❖ The need of design learning tools around demonstrators to help students with various part of the project. For example, design computer simulation or electronic systems to help them.
- ❖ Demonstrators need to be designed to prepare students to teamwork in projects in industry.

## 4 Analysis of mechatronics curricula

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### 4.1 Objective

This section aims at analysing existing mechatronics study programmes and at linking them with the findings described in chapter 2. The focus is on identifying the mechatronics competences that are at the forefront in existing study programmes and the IoT competences that are already part of them.

### 4.2 Dataset

Based on a survey form, all partners gathered information about existing mechatronics study programmes in different European countries. Information gathered for the different study programmes have been:

- ❖ Name of the curriculum
- ❖ Name of the Higher Education Institution
- ❖ Country
- ❖ Type of studies (Bachelor, Master, Other)
- ❖ Number of terms
- ❖ Lectures per predefined pillars and study year, with the following 11 pillars
  - Scientific basis (Math, physics...)
  - Technology (Materials, advanced mechanics...)
  - Programming and IT (C++, python, data management, AI...)
  - Electronics, Automatization. (Sensors, actuators...)
  - System engineering. (System simulation, mechatronics approach...)
  - Management (HR, project management...)
  - Language (English...)
  - Personal skills. (Scientific writing, oral presentation, Engineer's ethics, Bibliographic research...)
  - Links with the companies and placement
  - Practical work (e.g., mechatronic or IoT project, laboratory...)
  - Other subjects

The eleven pillars had been defined based on a pre-analysis of four mechatronics programmes.

DigiDemo partners gathered information about 36 Bachelor, Master and other mechatronics programmes in Austria, Denmark, France, Germany, Iceland, Norway, Spain, Sweden, and Romania, Table 4. The analysed mechatronic study programmes have been randomly selected by the partners, the only criteria for considering a programme has been the availability of the complete list of lectures taught.

**Table 4 Overview on analysed mechatronic study programmes**

Country	Bachelor	Master	Other
Austria	8	5	0
Denmark	2	3	0
France	0	1	1
Germany	7	0	0
Iceland	1	0	0
Norway	1	0	3
Spain	1	0	0
Sweden	1	0	0
Romania	2	0	0
<b>Total</b>	<b>23</b>	<b>9</b>	<b>4</b>

The analysed Bachelor study programmes from Austria, Iceland, Norway and Sweden last six terms, and the Bachelor programmes from Romania and Spain last eight terms. The German and Danish programmes last either six or seven terms depending on the HEI. Master studies last four terms, Figure 14.

The French technical educational system is not (yet) aligned to the Bachelor-Master-system. No initial mechatronics study programme after the A-level exams could be identified. The analysed study programmes are thus a three year mechatronics programme covering the third to the fifth year of studies, on top of another two-years engineering degree or preparatory cursus, and the second one is an integrated study programme over five years including a mechatronics specialisation during the 8<sup>th</sup> and 9<sup>th</sup> term.

Duration of Mechatronic study programmes

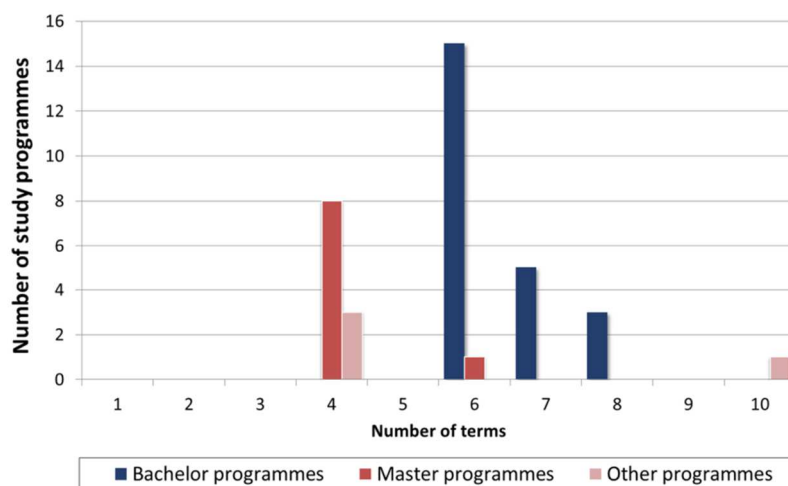


Figure 14 Duration of analysed mechatronic study programmes

Regarding the DigiDemo partners and their existing study programmes, the main target for the following analysis was put on Bachelor studies as DigiDemo partners are mainly offering this type of study degree.

### 4.3 Methodology

A semi-automated four-step process has been applied to exploit and concentrate the gathered data. The three preparatory steps have been:

- ❖ Identification of unique lecture denominations from the study programmes
- ❖ Consolidation of lecture denominations in sub-competence groups
- ❖ Grouping of sub-competence groups in the main competence groups as defined in chapter 2

Based on this consolidation work, the evaluation of the importance of sub-competences and main competences in the analysed study programmes had been realised.

#### Identification of unique lecture denominations

Denominations of lectures vary from one HEI to another as well as conditioned to the need of translating study programmes from national languages to English for further data exploitation. Thus, some lecture subjects exist with various denominations. E.g., the scientific basis lecture “Mathematics” turns up with 25 different denominations such as Calculus I, Calculus II, Higher Mathematics 1 (2, 3), Linear Algebra, Linear algebra, Analytical and differential geometry, Math, Mathematics, Mathematical analysis I & II, Mathematics and others. Similar situations can be observed for many other lectures.

A first step was thus to identify a list of unique denominators of lectures as they have been entered during the information gathering phase. The final list consists of 740 unique denominations of lectures for all 36 study programmes.

Regarding the following step, there was no need to delete or correct denominations with grammatical errors, as the unique denominations have then been consolidated in sub-competence groups.

**Consolidation of lecture denominations in sub-competence groups**

The second step was to attribute to each unique lecture denomination one of 72 sub-competences. The sub-competences have been created based on the existing lecture names. E.g., the 25 above mentioned mathematical lectures with their different writings all got the same sub-competence “Mathematics” for the further analysis.

Sub-competence groups have been added when new lectures made this useful as one did not fit to any existing group.

**Grouping of sub-competence groups in main competence groups**

The last consolidation step has been to link all sub-competences to the 15 main competences for mechatronic students based on the combined mechatronic/IoT scheme described in chapter 2.3 plus six further main competences. The associations between main and sub-competences are shown in Table 5.

In addition, the main competences have been grouped in five groups: General knowledge, mechatronics, mechatronics and IoT, IoT and miscellaneous.

**Table 5 Association of study sector, main competences and associated sub-competences**

Group	Main competence	Associated sub-competences
<b>General knowledge</b>	Scientific Basis	Chemistry / Electric basics / Material science / Mathematics / Physics / Statistics / System theory
	Mechanical CAD	CAD / Simulation
	Mechanical Systems	Fluidics / Kinematics / Linear systems / Mechanical systems / Mechanics (basics) / Optics / Thermodynamics
<b>Mechatronics</b>	Electronic Systems	Electric circuits / Electronics / Embedded systems
	Electromechanics	Electrical applications / Electrical engineering / Electrical machines / Electrical systems
	Control Electronics	
	Digital Control Systems	Data bus systems / Microprocessors
<b>Mechatronics and IoT</b>	Computers / Advanced computing	Computer Sciences / Computer Systems / Programming / Software Engineering
	Mechatronics / Smart systems	Automatisation / Autonomous systems / IoT / Optimisation / Product design / Product documentation / Robotics
	Control systems / Sensors and actuators	Control systems / Mechatronic Systems / Sensors and actuators / Signal processing

Group	Main competence	Associated sub-competences
IoT	User interface	Computer Aided Graphics
	Network, Network integration	Connectivity / Networks
	Cloud computing	
	Cybersecurity	Cybersecurity
	Data sciences	Artificial intelligence / Data processing / Information Engineering
	Blockchain technologies	
Misc	Soft Skills	Soft Skills / Thesis
	Management/Business	Business / ERP / Intellectual Property / Law / Management / Marketing / Project Management / Quality
	Professional experience	International / Work experience
	Industrial processes	Production systems / Supply chain
	Other	Environment / Medical systems / Misc / Project / Research

Table 5 shows three main competences – control electronics, cloud computing and Blockchain technologies – that are not present in the analysed study programmes. Whereas this is comprehensible for cloud computing and blockchain technologies that are clearly IoT domains, it is more difficult to understand for control electronics. This highlights the difficulty of the chosen approach of linking lecture names to sub competences and to main competences. No analysis of content has been realised, and the border between control electronics, control systems and digital control systems is not always clear.

#### 4.4 Identification of significance of competences in analysed study programmes

Once the beforehand mentioned consolidation done, sub and main competences have been linked to the individual study programmes, separated in Bachelor, Master, and Other studies to calculate a significance indicator for each sub and each main competence.

The significance indicator (SI) represents the percentage of study programmes having a given main or sub competence. E.g., the sub-competence ‘Electronics’ is present in 14 out of 23 Bachelor study programmes, thus the significance indicator is  $SI = 14/23 = 60,87\%$ .

The significance indicator allows to group competences in three categories highly present ( $SI \geq 70\%$ ), mainly present ( $30\% < SI \leq 70\%$ ) and less present ( $SI \leq 30\%$ ). Table 6 shows the sub-competences that are highly and mainly present in the analysed mechatronic Bachelor study programmes.

Nine competences are available in 17 or more of the analysed bachelor programmes (SI>70%), they are representing somehow the backbone of mechatronics bachelor studies. Seven of these competences are within the core mechatronics programme following the competence scheme from Vaccaro et al. (2016). Competences purely linked to IoT are not part of this backbone, only data processing competences are present in about 1/3 of the bachelor study programme. Within the second group, present in at least 30% of the analysed programmes, 15 competences can be found. This is an indicator for specialisation even within mechatronics bachelor programmes.

**Table 6 Sub-competences by group for Bachelor studies**

Group	SI >= 70%	30% <= SI < 70%
<b>General knowledge</b>	Mathematics (100,00%)	Physics (69,57%)
		Electric basics (30,43%)
		Material science (30,43%)
		Mechanical systems (65,22%)
		Fluidics (65,22%)
<b>Mechatronics</b>	Mechanics (basics) (100,00%) Electrical engineering (73,91%)	Electronics (60,87%)
		Simulation (56,52%)
		Microprocessors (43,48%)
		Kinematics (39,13%)
		Electrical machines (34,78%)
		Thermodynamics (30,43%)
<b>Mechatronics and IoT</b>	Computer Systems (100,00%) Product design (95,65%) Control systems (86,96%) Mechatronic Systems (73,91%) Sensors and actuators (73,91%)	Computer Sciences (60,87%)
		Product documentation (60,87%)
		Robotics (60,87%)
		Automatisation (43,48%)
		Programming (43,48%)
		Signal processing (39,13%)
<b>IoT</b>		Data processing (34,78%)
<b>Misc</b>	Soft Skills (86,96%)	Project (69,57%)
		Management (65,22%)
		Production systems (65,22%)
		Quality (65,22%)
		International (56,52%)
		Thesis (56,52%)
		Business (52,17%)
		Project Management (34,78%)
		Research (30,43%)

Within the analysed 9 Master programmes, the ‘backbone’ is even less pronounced with only four competences with a significance indicator above 70%, Table 7. The same statement can be done for the group with a significance indicator between 30% and 70%: Fewer competences are present in this group as for Bachelor studies. This is due to the multitude of different starting profiles for mechatronic master programmes, where students come from different engineering specialisations to get the mechatronics ‘add-on’.

**Table 7 Sub-competences by group for Master studies**

Group	SI >= 70%	30% <= SI < 70%
<b>General knowledge</b>		Mathematics (55,56%) Statistics (55,56%)
		Simulation (66,67%) Electronics (55,56%)
<b>Mechatronics</b>	Mechanics (basics) (77,78%)	Mechanical systems (55,56%) Electrical machines (33,33%) Microprocessors (33,33%)
		Product design (55,56%) Product documentation (55,56%) Robotics (55,56%) Sensors and actuators (66,67%)
<b>Mechatronics and IoT</b>	Computer Systems (100,00%) Control systems (88,89%)	
<b>IoT</b>		
<b>Misc</b>	Project (77,78%)	Management (55,56%) Production systems (55,56%) Thesis (55,56%) Quality (44,44%) Soft Skills (44,44%)

## 4.5 Discussion of results

The study presents a first approach based only on the names of lectures. Through this approach, the analysis could be done easily, but with two major disadvantages:

- The linkage ‘lecture names => sub-competences => main competence => group’ has been done in the best of the authors knowledge
- Basing the analysis only on the lecture names without analysing the lecture content does not allow identifying competences that are indirectly taught and not subject to a dedicated lecture.

Further analysis is thus desirable to confirm or precise the above-mentioned results.

## 5 Benchmark of DigiDemo partner programmes

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The DigiDemo partners' study programmes are in different manners in line with the beforehand identified competences. FHV and FSV offer mechatronic studies and UBB an IT programme with mechanical elements whereas UCN has a pure mechanical engineering degree and ESTA even a Sales Engineering degree. A benchmark shall help analysing the accordance of the project partners' study programmes with the results for competences for Bachelor studies (Table 6).

For the benchmarking approach, partners evaluated their programmes based on the identified competences with a SI > 30% obtained in the previous chapter. The detailed evaluation results are shown in Annex A.

For each study programme, two different indicators are calculated:

- **Completeness of study programme:** this indicator represents the percentage of accordance between taught competences and competences identified earlier in this report. To differentiate competences depending on their respective SI, a weighting has been introduced to calculate the reference score and the study programme score: SI > 70 got a weighting of 1, and 30 < SI ≤ 70 got a weighting of 0,5. The reference score is thus 22,5 points. The weighting is applied to a 1/0 score: 1 means competence is taught, 0 if competence is not taught.
- **Depth of teaching:** for each competence, a teaching weighting has been asked with 0 is not taught, 1 = weakly taught, 2 = normally taught and finally 3 = intensively taught (specialisations). The depth of teaching indicator is the mean of all competences with a weighing of at least 1. Thus, the possible minimum value is 1, and the maximum to be achieved is three when all competences are intensively taught. The standard value should be 2 (normal teaching).

The following study programmes have been analysed:

### **Product development and Integrative Technology (PRO) Bachelor, UCN, Denmark**

Product development and Integrative technology is part of UCN Technology & Business, department of Production & Design. The educational programme Product Development and Integrative technology (PTI) is a bachelor programme containing three different sub-directions (IT, energy, and Manufacturing & construction). The programme is a 1½ year (3. Semesters) 'top-up' programme, building on top of a 2-year mandatory educational programme within one of the three sub-directions. The one in focus here is the sub-direction within Manufacturing & construction, which focus on the manufacturing and development/construction of (mechanical) products. Students are enrolled once a year, with a limit of 35 students in each class.

### **Mechatronics Bachelor, FH Vorarlberg, Austria**

The Mechatronic Bachelor Program is the oldest study program of Vorarlberg University of Applied Sciences. It is included in the Department of Engineering. The qualification awarded is Bachelor of Science in Engineering (BSc). It is a full-time study with a duration of 6 semester and a workload of 180 ECTS. The intake is of approx. 35 students per year. Languages of instruction are German and English (in the 5. semester). No tuition fees apply. In the 5<sup>th</sup>

semester students can optionally spend a semester abroad at one of the partner institutions. A mandatory work placement is scheduled in the 6<sup>th</sup> semester with a workload of 20 ECTS.

**'Ingénierie d'Affaires Industrielles', ESTA Belfort, France**

The ESTA study programme 'Ingenierie d'Affaires Industrielles' (Industrial Sales Engineering) is a five-year diploma programme with a combination of technical and marketing / sales / management lectures that interchange every day. Studies have also a strong focus on international with intensive English and German or Spanish teaching, interculturality lectures and a mandatory 1-term placement in a non-French speaking country. Studies also include different placements (production, sales, marketing, sales engineering project in cooperation with companies). A class has about 50 students. As private school, students pay yearly study fees.

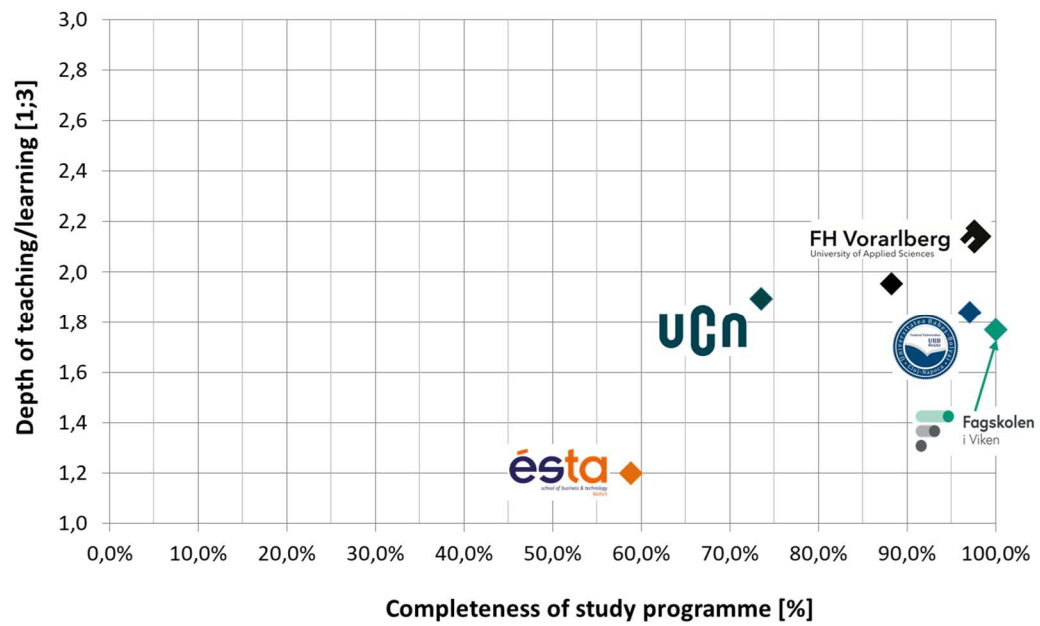
**Fagskolen I Viken, Norway**

The mechatronics course is a specialization under the Technology and Industrial Production (TIP) programme of Fagskolen i Viken at campus Kongsberg. The programme is over 2 years, where the first year is common for all TIP specializations. It has been on offer since 1995 and has served the regional industry with mechatronics professionals since the opening. The focus of the study is product development and industrial automation, and the qualification given is a candidate degree. In the last semester the students have a mandatory assignment which originates from the industry. Students are enrolled once a year and the class limit are 30 students.

**Centrul Universitat UBB din Resita, Romania**

The CU UBB Resita study programme 'Informatică industrială' (Industrial Informatics) is a four-year diploma program, combining three main technical areas informatics / electronics / mechanics through different lectures. Studies have also a strong focus on economic, certain lectures, especially in those having an optional character, are available for the students to develop these skills as well. Studies also include different placements (production, engineering project in cooperation with companies) after the 4th and 6th semester. A class has about 25 students with the study fees covered by the state, the so-called budgeted places, as well as students paying their yearly study fees (for places that exceed the state granted places).

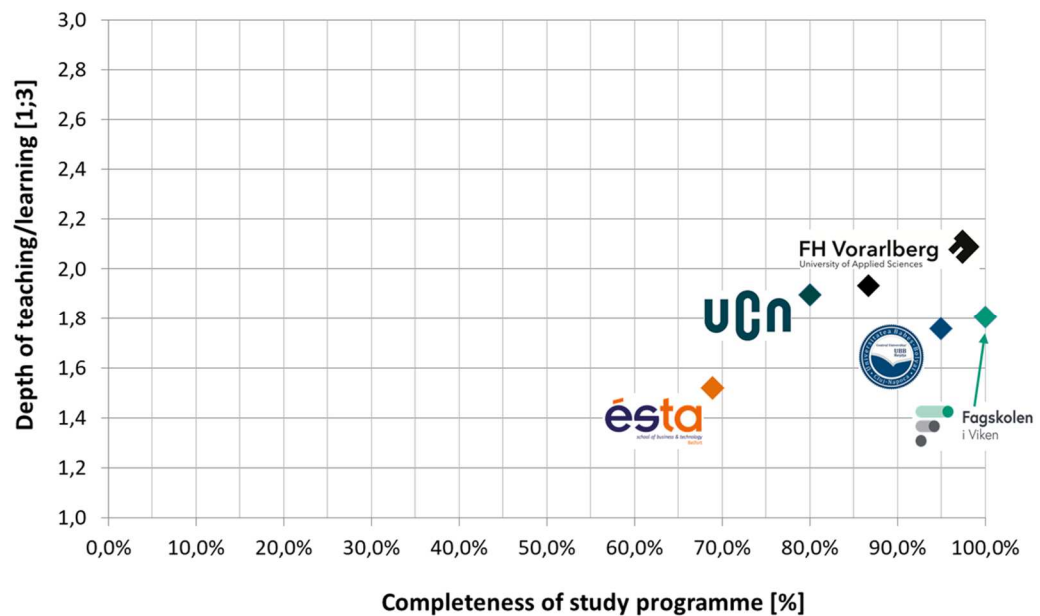
**Benchmark of existing partner HEI (Mechatronic and IoT competences)**



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**Figure 15** Benchmark results of partner programmes (Mechatronic/IoT competences)

**Benchmark of existing partner HEI (All competences)**



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**Figure 16** Benchmark results of partner programmes (all competences)

## Mechatronics and IoT: Literature and study programme analysis

Figure 15 and Figure 16 show the benchmarking results for selected study programmes at the partner institutions, where Figure 15 sets the focus only on identified general knowledge mechatronics and IoT competencies' groups, where Figure 16 also includes additional identified competencies of the Misc group (for details see Annex A):

- UCN: Product development and integrative technology (PRO)
- FSV: Technology in Production, specialization Mechatronics
- FHV: Mechatronics Bachelor
- ESTA: Industrial Sales Engineering (Ingénierie d'Affaires Industrielles)
- UBB: Industrial IT

The comparisons shows that the four pure engineering degrees show similar depth of teaching indicators ranging between 1,77 (FSV) and 1,95 (FHV) for mechatronic and IoT competencies only, and between 1,76 (UBB) and 1,93 (FHV) when looking on all competencies. Only the ESTA programme with its double focus on technology on the one hand and marketing and management competencies on the other one show significantly lower depth of teaching indicators of 1,20 and 1,52 respectively. This indicator catches up when looking on all competencies, as the Misc group is much more intensively represented than in the other study programmes.

Regarding the completeness indicator, a similar difference can be observed between the engineering degrees and the ESTA programme. Whereas the engineering degrees show completeness indicators between 73,5% (UCN) and 100% (FSV) for mechatronic and IoT competencies, the ESTA one is at 58,8%. Regarding all competencies, the completeness indicator of ESTA raises to 68,9% and closes up the ones from the engineering degrees ranging between 80,0% (UCN) and again 100% (FSV).

A look in the detailed data sheets, Annex A, shows that the high values from UBB and its 'Industrial IT' programme originate in different competencies than the ones of the other mechatronic oriented programmes. Whereas the last ones impart mainly mechanical and mechatronics knowledge and competencies, the UBB degree focusses more on the IT competencies where the mechanical and mechatronics competencies get lower depth of teaching values. Both approaches obtain similar results in the benchmarking process but with different focus. This fact highlights that a more detailed benchmarking process can help improving the comparison potential for study programmes.

## 6 Conclusion

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In the context of industry 4.0 and the improvement of technology with smart products and connected devices, DigiDemo is a European project co-founded by the Erasmus+ programme of the European Union aiming at responding to the needs of the industry for graduates skilled to design, develop and sell connected products.

Projects being one important aspect of teaching mechatronic skills, the partners develop a set of mechatronic demonstrators to be used for teaching. Regarding the findings of this study, at least some demonstrators will expressly address additional skills from the IoT domain such as e.g., network integration.

The benchmark of the partners' study programmes shows a strong accordance of the four engineering study programmes from UCN, FHV, FSV and UBB, even if differences can be observed. The atypical programme from ESTA Belfort has much lower indicators, as well for the completeness of the programme compared with the 'standardised' mechatronic competences as with for the depth of teaching. Benchmarking of the partner study programmes thus highlights the gaps to be filled to teach all mechatronic competences.

The final conclusions out of the study are the following:

- There is a necessity to design hybrid demonstrators using competences from the mechatronics domain, but also integrating competences from the IoT domain to enable students to design, develop and sell connected products. This is also valid for the benchmarked mechatronic Bachelor.
- Demonstrators must address students at different levels of their studies, with simple demonstrators at the beginning up to complex ones in the last study years.
- If project partners want to evolve their programmes to full mechatronic study programmes, efforts are necessary to integrate missing competences.

The identification process of core competencies for future mechatronic students allowed highlighting the need to add IoT competencies especially focusing connectivity of products to the standard mechatronic programme. Further optimisation and work are suggested to improve and evolve both the identification process for competencies and the benchmarking approach.

The objective of the DigiDemo project is to develop demonstrators allowing better combining both approaches for highly qualified graduates.

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## Annex A Benchmark sheets

### Study programme, UCN

	DigiDemo partner programme benchmark			
	Select partner: UCN			
Analysed programme: Product development and integrative technology (PRO)				
Group	Sub competence	Weighting	Competence taught in study programme? 0 = Not taught 1 = weak teaching 2 = normal teaching 3 = strong teaching	Benchmarking value
General knowledge	Mathematics (100,00%)	1	2	2
	Physics (69,57%)	0,5	1	0,5
	Electric basics (30,43%)	0,5	0	0
	Material science (30,43%)	0,5	3	1,5
Mechatronics	Mechanics (basics) (100,00%)	1	3	3
	Electrical engineering (73,91%)	1	1	1
	Mechanical systems (65,22%)	0,5	3	1,5
	Fluidics (65,22%)	0,5	1	0,5
	Electronics (60,87%)	0,5	1	0,5
	Simulation (56,52%)	0,5	3	1,5
	Microprocessors (43,48%)	0,5	0	0
	Kinematics (39,13%)	0,5	1	0,5
	Electrical machines (34,78%)	0,5	0	0
	Thermodynamics (30,43%)	0,5	2	1
Mechatronics and IoT	Computer Systems (100,00%)	1	0	0
	Product design (95,65%)	1	3	3
	Control systems (86,96%)	1	1	1
	Mechatronic Systems (73,91%)	1	2	2
	Sensors and actuators (73,91%)	1	0	0
	Computer Sciences (60,87%)	0,5	0	0
	Product documentation (60,87%)	0,5	3	1,5
	Robotics (60,87%)	0,5	1	0,5
	Automatisation (43,48%)	0,5	2	1
	Programming (43,48%)	0,5	1	0,5
IoT	Signal processing (39,13%)	0,5	0	0
IoT	Data processing (34,78%)	0,5	2	1
Misc	Soft Skills (86,96%)	1	2	2
Misc	Project (69,57%)	0,5	2	1
Misc	Management (65,22%)	0,5	2	1
Misc	Production systems (65,22%)	0,5	2	1
Misc	Quality (65,22%)	0,5	2	1
Misc	International (56,52%)	0,5	2	1
Misc	Thesis (56,52%)	0,5	2	1
Misc	Business (52,17%)	0,5	2	1
Misc	Project Management (34,78%)	0,5	2	1
Misc	Research (30,43%)	0,5	1	0,5
		<b>Mechatronics &amp; IoT only</b>	<b>complete programme</b>	
<b>Depth of teaching/learning</b>		1,89	1,90	
<b>Completeness of mechatronics programme</b>		73,5%	80,0%	







