# Adapting Electrical and Electronic Engineering Curriculum Towards IoT and Cyber Physical Systems Themes

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## INTRODUCTION

In our daily lives new systems based on emerging technologies are being introduced to facilitate our tasks in different sectors such as living, mobility, energy, healthcare and industry just to name a few. These systems are labelled as Internet of Things (IoT) systems and/or Cyber Physical Systems (CPS). The design and development of these systems and their successors demands new expertise and skill sets from the engineers involved in these application areas. Fontys University of Applies Sciences therefore continuously searches to update its current undergraduate Electrical and Electronic engineering curriculum according to the new trends.

Most of the applied science universities in the Netherlands including Fontys are involved in a discussion to define the Body of Knowledge and Skills (BoKS) of an electrical and electronic engineering graduate [1]. The proposed system defines two levels; where the first level as shown as horizontal slap in Fig. 1, describes the common basic BoKS for all graduates irrespective of their specialisation. The second one describes the BoKS's specific to their specialisation. These BoKS's can provide some information to companies regarding what to expect form an electrical and electronic (EE) engineer in terms of knowledge and skills.

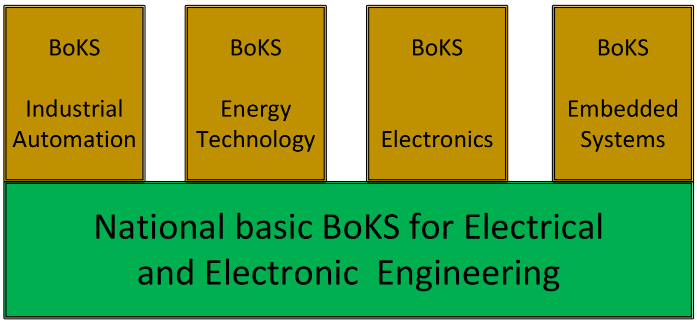


**Fig. 1 BoKS of an electrical and electronic (EE) engineering graduate of an applied science university with minimal commonality**

Each university can choose specialisations which are aligned with their surrounding industries. Fontys EE department chose to redesign its EE engineering curriculum to provide two specialisations above the common BoKS, namely Embedded Systems and Electronics BoKS's. This research will help Fontys EE department to reshape the chosen specialisations in relationship to IoT and CPS themes.

This paper is organised as follows: Section I describes the background information necessary to motivate this research and Fontys EE curriculum will be introduced in more detail. In section II, an overview of other universities' curriculum design is given. Section III describes the designed survey and the results collected with varying inputs from representatives from industry, lecturers and Fontys EE engineering students. Section IV describes the analysis of the collected data. Finally, Section V discusses the evaluation of the results, and Section VI summarizes the main conclusions and recommendations of the paper.

## 1 BACKGROUND INFORMATION

With the rapid advances in smart sensors, computation and wireless communication technologies, there is a strong trend to enhance our lives with smarter systems. Fig. 2 shows how the hype of different technological trends changes over time. Autonomous vehicles and Internet of Things are clearly on the peak of the hype cycle, showing that these trends are relevant in today's world, and directly linked to this research [3]. Smart systems connect systems together in an intuitive way to provide us with ambient intelligence. The Internet of Things (IoT) is connecting a greater number of devices every day to make our lives easier [2] . Cyber-physical systems (CPS) integrate and coordinate the dynamics of physical systems with computational and networking abilities to enable intelligent systems [3]. Some examples of CPS's are smart homes, smart cities, healthcare robots, and autonomous vehicles. Also, robots for domestic or industrial use are performing activities without the need of human interaction, making them effortless to manage.

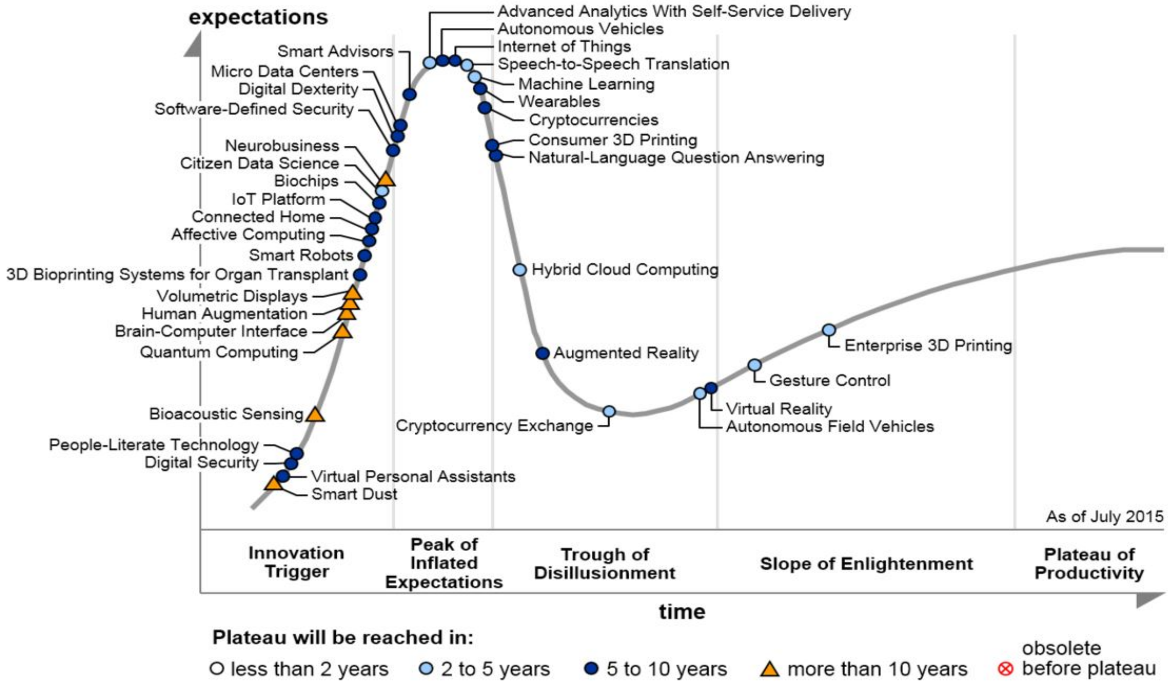


**Fig. 2 Gartner Hype Cycle for Emerging Technologies, 2015 [4].**

CPS's are a key technology to enable more flexible production and allow faster prototyping in 3D Printing. While CPS's are able to work autonomously, IoT is all about connectivity. Cloud computing allows small devices to make smart decisions and interact with the environment.

## 1.1 Fontys EE Engineering Curriculum

The regular route of the EE engineering programme can be done in 4 years (8 semesters) where 240 European Credit Transfer and Accumulation System (ECTS) credits need to be completed. It consists of a major of 210 ECTS-credits spread over 7 semesters and a minor of 30 ECTS-credits, i.e. one semester as shown in Fig. 3.

In the first four semesters, students have a fixed programme covering the basic Body of Knowledge and Skills (BoKS) which was approved by all (18) EE Universities of Applied Sciences in the Netherlands [1]. Fontys EE Engineering department provides Analogue Design and Embedded/Digital Design specialisations. In this period, students have several courses and practical projects. A large part (41%) of their workload is in projects. In the first year they learn to work in teams and in the second year they have four industrial projects to get in touch with the way of working in the industry and to have experience with the latest technologies and tools. The project work is supported by relevant design courses. With these projects, students can start working on their specialisation and areas of interest. In these industrial projects students integrate theory and practice in a rich context and are able to choose which areas are suitable for them.

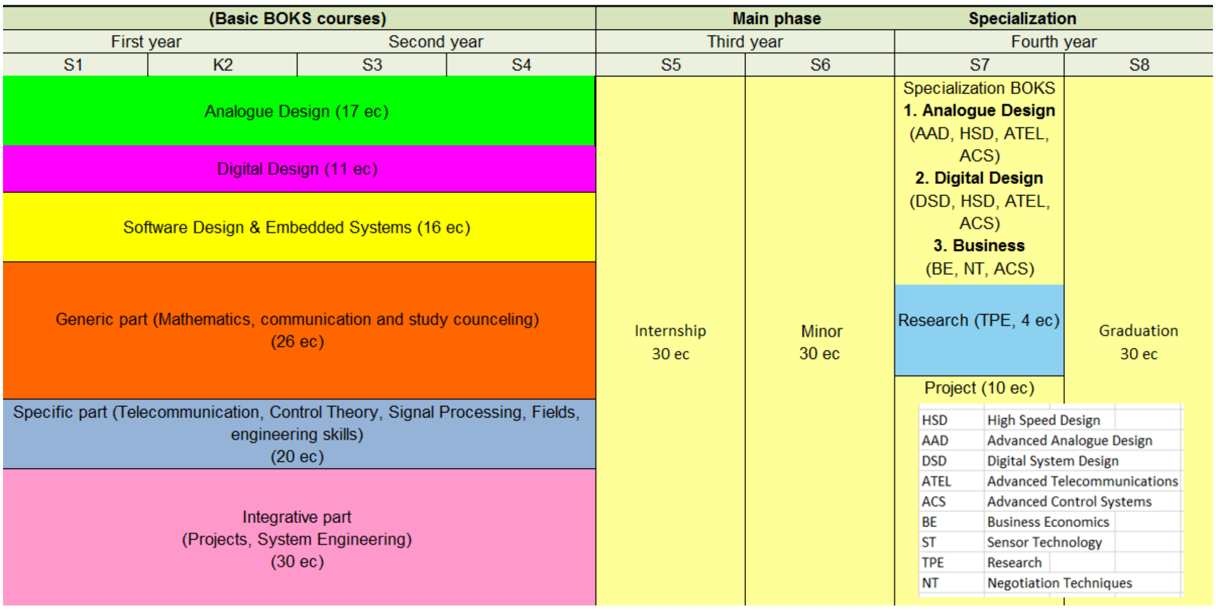


**Fig. 3 The distribution of the credits of Fontys E&E engineering curriculum.**

Semester 5 to and including 8 can be completed in the direction of the chosen specialisation. The students work in semester 5 as a trainee in an industry sector to gain real-world experience. Semester 6 is minor semester where the students choose subjects according to their interest, either at Fontys or other Universities. The minor can be used to broaden the student's scope, such as Business, or to dive deeper into engineering topics such as Digital Systems, Embedded Systems, Analogue Design, etc. Semester 7 is the real specialisation semester where subjects and projects can be selected depending on the chosen specialisation. Finally, semester 8 is the graduation phase where students do a 6-month internship with a thesis in the industry.

As a result, the education at Fontys is practical-driven one. Each course has a practical and theory part, but on top of that projects and industrial internships bring a real-world engineering experience which puts the theory and practice in a rich context [5].

## 2 OTHER UNIVERSITIES CURRICULA DEVELOPMENT

In literature there are quite few examples regarding integrating IoT and CPS in an EE engineering curriculum. For example, the authors of [6] describe their experience in integrating IoT in their curriculum. They designed a course about IoT where they covered IoT related programming and industrial design. The programming part is about cloud computing with Scala and interfacing with sensors. Lightweight IoT protocols like 6LoWPAN and ZigBee are used. The industrial design part is about building an industrial-grade IoT application. The paper states the students had a good experience doing the IoT course. Also the authors of [7] describe how CPS impacted their curriculum and courses. At the University of Emden, they integrated CPS into their curriculum in the form of projects and lectures in various Master degree programs. It is mostly based around networking, programming and robotics in an industrial context. The methodology is interesting and somehow similar to the previous paper. What they have in common is that they both provide a special program outside of the traditional curriculum in the form of a course and a Master degree respectively.

The authors of [8] on the other hand, approached the issue in a different way. Instead of having one dedicated course or master about the subject, they expose undergraduates as early as possible to the subject with background courses. More advanced courses are given at graduate level. This different approach is definitely interesting.

The companies Metatronics and Mark Global in The Netherlands are believers of the big IoT promises for the future [9]. They see organisations struggle with challenges to get from zero to one, targeting their opportunities and exploring IoT related ideas and concepts. From surveys and interaction with their customers, Metatronics and Mark Global found the top four key dimensions when starting an IoT related project with a customer:

1. IoT Strategy
2. IoT Infrastructure
3. IoT Skills & Capabilities
4. IoT Business Processes

Fontys EE engineering wants to focus on the technical aspects of IoT and CPS. As one can see in these 4 dimensions, the EE engineering students should be trained in Infrastructure and skills as they fit closely to the goals of the Fontys EE curriculum.

It is also necessary to find out whether more general dimensions such as Strategy and Business Processes should be included in the curriculum as well. The survey should include a question about this, not only towards industry, but especially towards the students, asking them whether or not they have interest in these areas.

Combining the elements discussed so far (our current curriculum, information from other universities and a company's view) the blue print of the survey is clear. The survey was created with the following main focus areas: software engineering, digital systems, signal processing, data & telecommunication, analogue systems, embedded systems and professional development. These themes were used in the survey, with approximately 5 sub questions per focus area, to get more specific results.

## 3 SURVEY AND RESULTS

Three groups of participants were targeted, namely the industry, EE engineering lecturers, and third and fourth year Fontys EE engineering students, to give different views on this matter. It was decided to use the same survey for the industry, lecturers and the students, so that comparisons could be easily made. The selected industry group contains the industrial advisory committee for Fontys engineering, Fontys PROUD alumni [10], and selected experts from the industry in Brainport region [11]. The selected EE engineering lecturers' groups consists of Fontys lecturers and some EE engineering lecturers from the applied science universities in The Netherlands.

The participants had to answer questions and sub questions in six categories, as shown in Table 1. The main questions can be answered by choosing either Yes or No. However, for all of the sub questions in all categories, the participant can choose a value on a scale of 5-1 where (5) I fully agree; (4) I agree; (3) Neutral; (2) I partially disagree; (1) I disagree. Fig. 4 shows the results collected from the three groups i.e. the industry, lecturers, and students regarding the main questions. The survey received 31 responses from students, 14 responses from the industry and 22 responses from EE engineering lecturers.

**Table 1** The questions that were used in the survey. Note that every sub question is motivated with extra explanation to provide a context for the question. This info is not presented in the table to make it easy to follow.

| Number | Question |
|---|---|
| MQ1 | **Do you think software engineering is important for IoT and/or CPS?** |
| **1.2** | Model-Driven development |
| **1.3** | Cloud computing and Big Data |
| **1.4** | Software security and data safety |
| **1.5** | Artificial Intelligence |
| **1.6** | Designing with software frameworks |
| MQ2 | **Do you think digital systems and signal processing are important for IoT and/or CPS?** |
| **2.2** | System on a Chip |
| **2.3** | Soft- and Hard-core processor Design |
| **2.4** | Interfacing with sensors |
| **2.1.1** | Signal processing algorithms |
| **2.1.2** | Image processing and Machine Vision |
| MQ3 | **Do you think data- and telecommunication is important for IoT and/or CPS?** |
| **3.2** | Software Defined Radio (SDR) |
| **3.3** | Low power networks en RF transceivers |
| **3.4** | Radio Frequency PCB and antenna design |
| **3.5** | Lightweight internet protocols |
| **3.6** | Distributed control and monitoring |

| Number | Question |
|---|---|
| **MQ4** | **Do you think Analog Systems are important for IoT and/or CPS?** |
| 4.2 | PCB Design |
| 4.3 | High efficiency power conversions |
| **MQ5** | **Do you think Embedded Systems are important for IoT and/or CPS?** |
| 5.2 | Device drivers |
| 5.3 | Energy efficient software development |
| 5.4 | Real-time aspect and multithreading |
| 5.5 | Embedded Linux & Android |
| 5.6 | Human machine interface and user interface |
| **MQ6** | **Do you think professional development is important to IoT/CPS?** |
| 6.2 | Engineering ethics |
| 6.3 | Lifelong learning |
| 6.4 | Professional competences |

All of the main questions received a high score regarding their importance to the IoT and CPS themes as shown in Fig. 4. The YES/NO score is converted into a number with the following formula: % of interviewee giving the answer "YES" times 5 points. It can be noticed that the industry group rated MQ3 and MQ4 a little bit less than the other main questions. Both the lecturers and the students are almost agreeing with their rating regarding the six main questions.

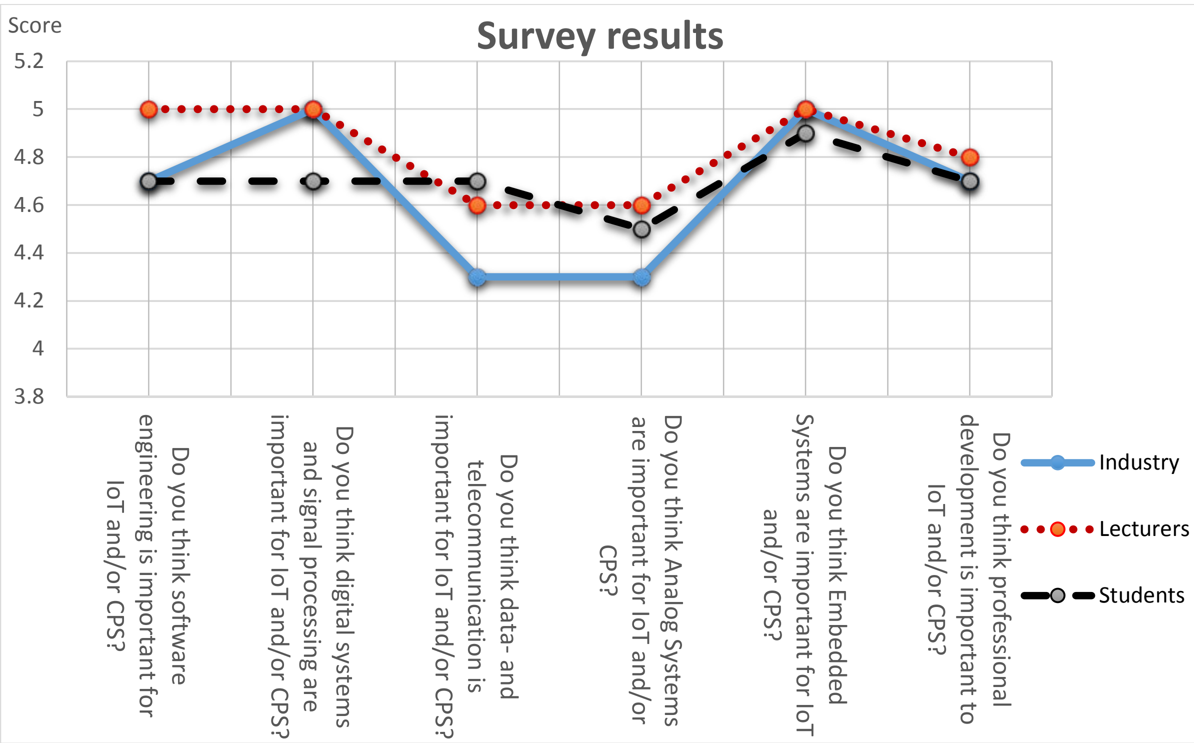


**Fig. 4 The results from the industry, E&E lecturers and students regarding the main survey questions.**

The results collected from the three groups i.e. the industry, lecturers, and students regarding the sub questions within the aforementioned main questions is shown in Fig. 5. In general, all of the sub questions received a score of 3 or more regarding their importance to the IoT and CPS themes with one exception. The exception is related to sub question 1.3 “Cloud computing and Big Data“ where the lecturers gave it a score of 2.25 while it received 3.0 and 3.25 from the students and the industry respectively. This may be is related to combining “Cloud computing and Big Data“ in one question. They are inter-related but for some people they are completely different. This combination may have caused confusion, it was better if they were separated in two sub questions.

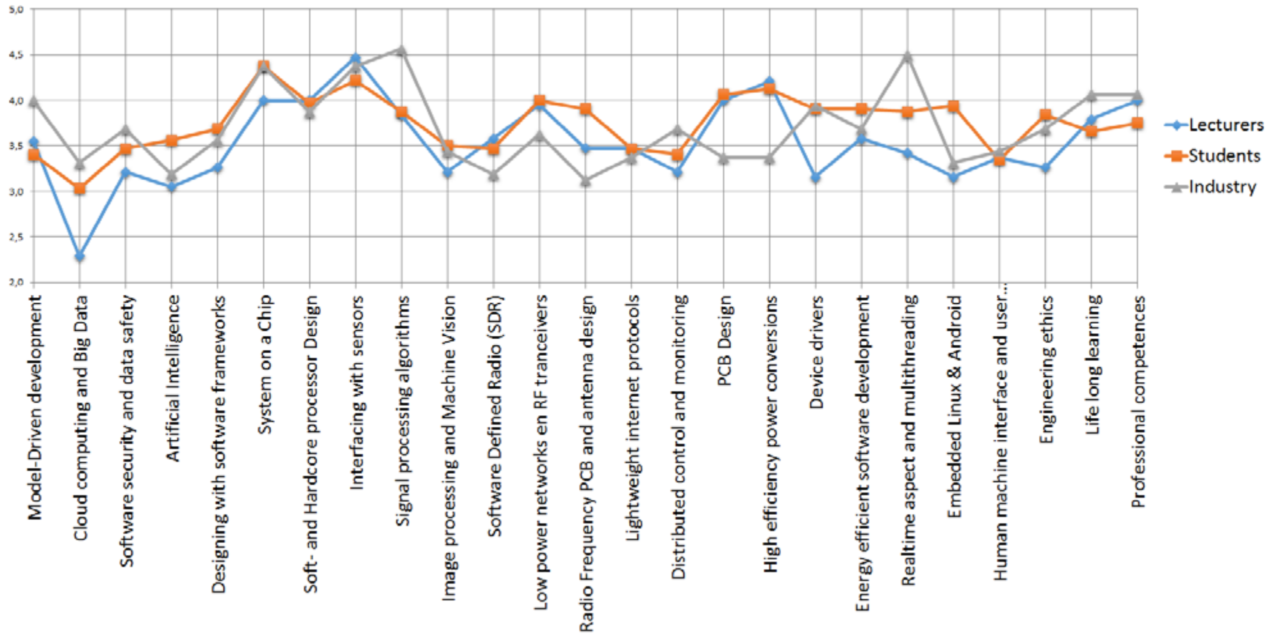


**Fig. 5 The survey results regarding the sub questions from the industry, lecturers and students. The average scores can be between 1 to 5 with an average score of 3.0 meaning neutral feedback.**

In the following sections, the received data from the three groups will be analysed and compared per main question and its sub questions.

### 3.1 Software Engineering

In general, all of the sub questions related to software engineering received a score higher than 3.0 indicating that these topics should be considered in the EE engineering curriculum. Note that the industry indicated with an average of 4 for the sub question 1.2 “model driven development (MDD)” should be in the EE curriculum. However, sub question 1.3 “Cloud computing and Big Data“ received from the lecturers a score of 2.25 while it received a score of 3.0 and 3.25 from the students and the industry respectively. Noting that the lecturers group comprises lecturers with different specialisation areas, it is most likely that some lecturers considered this mainly as an ICT specialisation.

### 3.2 Digital systems and signal processing

Overall, all of the questions related to this main question received a score higher than 3.0 indicating that these topics should be considered in the EE engineering curriculum. Note that the industry, lecturers and students are agreeing that sub question 2.2 the design with (System on Chip) SoC should be part of the EE curriculum where it received an average score of more than 4. Also the same applies for sub question 2.4 "interfacing with sensors" and sub question 2.1.1 "Signal processing algorithms."

### 3.3 Data- and Telecommunication Engineering

All of the questions related to this main question received a score higher than 3.0 indicating that these topics should be considered in the EE engineering curriculum. Note that the students ranked sub question 3.4 "Low power networks and RF transceivers" the highest with a score of 4.

### 3.4 Analogue Systems

All of the questions related to this main question received a score higher than 3.5 indicating that these topics should be considered in the EE engineering curriculum. The scores from the industry, lecturers and students are highly correlated which indicate that these topics should be considered in the EE curriculum. Note that the average score from the groups for sub question 4.3 "High efficiency power conversions" is more than 4.

### 3.5 Embedded systems

All of the questions related to this main question received a score higher than 3.5 indicating that these topics should be considered in the EE engineering curriculum. The scores from the industry are relatively higher than what was received from the lecturers.

### 3.6 Professional development

The questions related to this main question received a score higher than 3.5 indicating that these topics should be considered in the EE engineering curriculum. The scores from the industry are relatively higher than what was received from the lecturers. Note that the average score from the groups for sub question 6.4 "Professional competencies" is more than 4.

## 4 ANALYSIS

As it was noted before, the main goal of this research is to identify the kind of topics/activities/assignments that can be used to shape the specialisation BoKS's chosen by Fontys EE engineering department namely Embedded Systems and Electronics BoKS's shown in Fig. 1. To highlight the importance of the sub questions to the interviewed groups, the sub questions are clustered into three clusters based on their average scores. The number of sub questions that had a score higher than 4 is four sub questions and they are labelled cluster I. However the number of sub questions that have an average score between (3.5 , 4.0) is 14 sub questions and they are labelled as cluster II. Six sub questions received an average score below than 3.5 and they are labelled cluster III.

The results of this survey make it clear that some changes in the current EE engineering curriculum are highly recommended. It was decided to provide recommendations for changes regarding courses/projects/assignments based on sub questions from cluster I and II that have an average score more than 4.0 and between (3.5, 4.0) respectively (Fig. 6). Those topics, directly related to the sub questions, written in italics belong to cluster I and non-italics topics belong to cluster II.

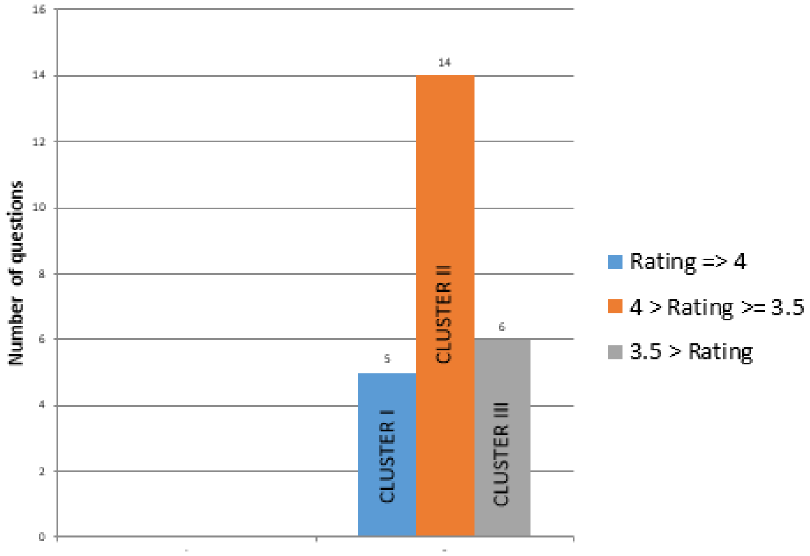


**Fig. 6 displays the average scores in three clusters where the y-axis gives the number of questions in the cluster.**

Since the students in the specialisation semester S7 do not have an opportunity to follow a course targeting advanced topic in embedded systems, a new Advanced Embedded Systems (AES) course is proposed to cover among other things topics identified in the survey:

- *Designing with SoC,*
- *Interfacing with sensors,*
- *Soft- and hard-core processor Design,*
- Device drivers

The same is applicable to real-time systems where in the current curriculum there is no course covering these topics, a new course Real Time Systems and Modelling (RTSM) to cover topics among other things such as:

- *Model-Driven development*
- Real-time aspect and multithreading
- Designing with software frameworks
- Energy efficient software development
- Lightweight internet protocols

Also the following courses in the current curriculum need to be modified to cover the topics that received an average score more than 3.5 follows:

- AAD Advanced Analogue Design
  - o *High efficiency power conversions*
  - o PCB Design
- DSD Digital System Design
  - o *Signal processing algorithms*
- ATEL Advanced Telecommunications
  - o Software Defined Radio (SDR)
  - o Low power networks and RF transceivers
  - o Radio Frequency PCB and antenna design
- ACS Advanced Control Systems

  - *Signal processing algorithms*
  - Distributed control and monitoring
- STBS Advanced Sensor Technology for Mechatronics Systems
  - *interfacing with sensors*
  - *Signal processing algorithms*

To provide the students with an environment that is beneficial for their future profession it was decided to create a “Be Creative” minor where students in groups of 4-6 students work for one semester on a challenging project aligned with the industry/universities to cover among other things topics such as:

- *Professional competences*
- Lifelong learning
- Engineering ethics

Working on projects is an excellent opportunity for the students to design systems by integrating the knowledge and skills acquired from the different learning experiences that the students have in their study. Also it exposes them to modern tools and technologies that are related to their projects [12]. As outlined before, in the current curriculum the students can do EXPO projects in the first two years and IPD projects in S7. In the IPD projects students are expected to work more independently to learn new things. It is highly recommended to provide them with open ended challenging IPD projects to enable them to solve real-life problems using the latest technologies in the field of IoT and CPS.

For students who want to choose a specialisation BoKS, the department should guide them in their choices. For those students that would like to specialize in the Embedded Systems BoKS, the recommended courses during the specialisation semester are AES, RTEM, TPE and a dedicated embedded system IPD project and they can choose two elective courses from the EE department. When a student chooses the Electronics specialisation BoKS, the recommended list of courses is AAD, ACS, TPE and dedicated electronic IPD project and they can also choose two elective courses from the department.

## 5 CONCLUSIONS AND RECOMMENDATIONS

One of the challenging tasks for most of the universities is to provide an attractive EE engineering programme that can help the students to take leadership roles in the relevant industries. Fontys EE engineering department is very active in investigating the best possibilities to achieve this goal. During this research, a survey regarding CPS and IoT themes was created and used to get more confidence about the dominant topics relevant to these themes and their inter-relationships with the EE engineering educational system. This provided an opportunity to see if the interviewed groups i.e. the industry, lectures, and students have somehow the same views regarding the important EE engineering topics. The results from this survey proved that discrepancies between the three groups are minimal. All of the interviewed groups agree that all of the listed topics are relevant to EE engineering graduate but with different scale of importance.

The current EE engineering curriculum is missing some of the topics relevant to IoT and CPS. Therefore, it is highly recommended to introduce some changes in S6 and S7 semesters:

1. **AES course:** A specialisation course in S7 covering topics related to advanced embedded systems such as designing with SoC, hardware and software partition, digital signal processing, etc.
2. **RTSM course:** A specialisation course in S7 covering topics related to real time aspects and real time OS can be added to the S7 elective course.
3. Also some content changes were recommended to the current courses offered by the EE department as discussed.
4. Seeing the integrative learning experience that can be provided by projects, it is highly recommended to define S7 IPD projects that provides some challenges to the students in the field of IoT and/or CPS.
5. It is highly recommended to provide a new minor “Be Creative” where the students can work on a project for one semester. The topics of the projects that can be dealt with in this minor can be chosen by the students based on a collection offered by Fontys in collaboration with the industry/universities.
6. The guidelines for choosing courses in the specialisation BoKS should be adapted to the new situation.
7. Since the students in the first two years are working on four EXPO projects it is recommended to provide some projects in line with the chosen specialisation BoKS’s.

Overall it can be concluded that updating and future checking the curriculum this way is giving fast and good directions. So from literature review, finding out the hot topics in the field, and checking these topics with all stakeholders is giving the right track. The final conclusions were also checked with Fontys Engineering Advisory Board. In this way the proposals were checked against the knowledge and skills needed in companies in the Brainport Area; the working field of our engineers. With their “GO”, the implementation phase has been started.

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