Learning to Conceive, Design, Implement and Operate Circuits and Systems

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Outline

- Introduction/Motivation
  - Core skills, transversal -soft-skills, design-centric skills
- Conceive, Design, Implement and Operate Circuits/Systems
  - The CDIO initiative
  - Learning to Design
  - Learning to Conceive
  - Other aspects of a CDIO-inspired Curriculum change
- Case example: CDIO in Electrical Engineering at UPC
  - Comparison of skills provided by different frameworks
  - Curriculum architecture
  - Introduction to ICT Engineering
  - Basic ICT Engineering Project
- Conclusions and future activities
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Motivation (I)

Scenario: Current debate about which transversal competences and skills should be acquired by Electrical Engineering students and which methodologies should be considered to induce their learning

Statu quo: to consider the inputs from various stakeholders - in particular from employing companies and from the Society at large-, which state that EE students are already generally well prepared in core technical skills but that they should enhance their personal (communication) and interpersonal (teamwork) skills.

Certainly there is room for improvement in this dimension, since the fact that EE studies are particularly challenging has resulted in the past in the fact that a relevant part of students were deficient in social skills. However, the addition of such personal and interpersonal skills, although of interest, is understood to be common to all professions.

The question arises of whether EE Schools, which in the past have concentrated in analytical skills, can now, beyond adding soft skills, do better as regards technical contents and skills which are specific to Engineering, such as DESIGN
Motivation (II)

There is a new trend, which identifies that beyond core technical skills (as conventionally included in Engineering Colleges) and transversal soft skills (as more recently demanded by Society and companies), the transversal engineering competences of Conceiving, Design, Implementing and Operating Circuits and Systems are key for a comprehensive electrical engineering education, since they constitute the backbone of engineering.

Need to further explore and share these alternative engineering-centric skills and discusses learning methodologies and activities, best practices and experiences oriented to recover these four skills in Engineering Schools.

These aspects, which complement the issue of which technical contents should be included/modified/eliminated in engineering curricula, affect both courses and curriculum architecture (both by revisiting already existing course contents and adding specific project-based ones).

Learning methodologies go beyond learning tools (such as e-learning, or distance-learning), and encompass (design) methodologies.

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Conceive, Design, Implement and Operate Circuits/System

The CDIO initiative

- An initiative exists which originally comes from Aerospace and Mechanical Engineering disciplines, namely the CDIO approach, which is cooperatively formed by an open consortium that includes MIT, CU Boulder, KTH, Chalmers and Univ. Auckland, among a growing set of Universities.
- This engineering education methodology considers a profound and comprehensive change in learning contents and methodologies which is common to all engineering disciplines. One of the core emphasis is in design skills, together with a project-based perspective for tackling complex systems.

Conceive, Design, Implement, Operate

Graduating engineers should be able to conceive-design-implement-operate complex value-added engineering systems in a modern team-based environment.

Conceive, Design, Implement and Operate Circuits/System

The CDIO initiative

- One of the emphasis of the CDIO initiative is to provide skills to develop products, this is, of complex systems that target the market and/or Society.
- In that interpretation, C, D, I, O correspond to the four main phases in project development oriented to products, following the well-known "V"-shape project description

- Compatible with the CDIO rationale, in this work we explore the complementary interpretation of CDIO as the four transversal competences for an engineer, which in particular can be applied to circuits and (complex) systems.

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Conceive, Design, Implement and Operate Circuits/System

Learning to Design (I)

- The core task of an engineer, and in particular of an EE engineer, is to design.
  - As early identified by the (late) pioneer Caltech professor David R. Middlebrook, Engineering Schools migrated decades ago from an scenario in which design was all based in practice and intuition, into a scenario in which, by incorporating the scientific method thorough analytical rigor, students learn to analyze circuits but somehow fail to design them.
- To avoid that algebra and analysis mask the design process, it was proposed to use low-entropy expressions aimed to design-oriented analysis, to improve the intelligibility of the analytical models describing circuits and systems.
- The cognitive processes related to the design creativity are partially subconscious, design is not to be mystified. It is not an art or magic, but rather it requires shifting the mindset from analysis to synthesis;
- For synthesis the aim is not to describe analytically per se a circuit or a system but to understand the circuit to be able to dimension its parameters (the lower design layer, parametric design) and/or modify its structure (functional design).
- A student can naturally have a certain talent to learn design skills, but they can certainly be fostered through exposure to design problems (particularly to open-ended design problems).
- Experiences and thoughts aligned to these arguments can be found in recent works within the CAS discipline.

Learning to Design (II)

- A distillation of the design process evolves into the concept of structured design, which has been tackled by the CAS research community.
- Structured design is a two-fold process, namely: (1) first to appropriately model the interdependencies among a set of performance metrics and the variables that form the multidimensional input design space. (2) Afterwards, appropriate application of optimization tools which lead to a final optimum design in terms of performance metrics. The second part of the design process can be thus carried out automatically, so that the optimum design process relies on the modeling process. This modeling process can be carried out in two ways: (1) by hand calculation, in which the human designer should derive an intuitive low-order analytical model via low-entropy expressions, or (2) by computer-based simulations, which come into play to characterize the model when more sophisticated dependencies are required.
- Structured design is a must in high-order hierarchy and complex systems, as in aerospace applications and multidisciplinary EE projects. Last trends in structured design consider a circuit/system co-design perspective with a translayer approach, in which a conceptual and modeling bridge is built among circuit-level characteristics and system-level performance metrics. These approaches can naturally be incorporated in capstone projects.
Learning to Conceive

- Curricula renovation usually includes creativity and entrepreneurship to promote creation of added-value products or even businesses.

- How to stimulate creativity in a formalized manner --or even with the scientific method-- at a circuit or system technical level?

- When facing a design exercise, either the system architecture or the circuit topology is given a priori.

- Exploring the design space thoroughly can indeed be a way to understand how to circumvent a given circuit or system fundamental limitation, thereby paving the way to conceive an innovative circuit-level or system-level solution that can outperform the precedent circuit or system.

- The bottom-line of this approach is hence not to teach/learn the "know-how", but to add the "know why", which naturally leads to the question "what if?" - the answer of which is the seed of conceiving novel designs.

Learning to Conceive (II)

- Methodological techniques to cultivate in students creativity skills exist which can be incorporated in active learning courses. At a project or product level, usually brainstorming is considered as a technique to generate new ideas through -versed- debate, which can be judged afterwards through critical thinking to select candidate solutions.

- In particular, analogy is a very powerful tool to conceive novel circuits and systems.

- Once it is understood the "how?" and the "why?" of a given circuit/system principle, in order to answer the "what if?" question, analogies to solutions in other subtopics are a way to provide a solution, and the students should soon learn such cognitive technique.
Conceive, Design, Implement and Operate Circuits/System

Other aspects of a CDIO-oriented Curriculum change

• Incorporating any additional content to a curricula or a course, by virtue of the communicating vessels principle, is seemingly detrimental to other contents, which should be reduced in extension or depth. A solution to such situation considers multiple-impact learning activities.

• Such activities are devised so that concurrently design skills together with soft skills are covered and mutually reinforced while revisiting core technical skills.

Conceive, Design, Implement and Operate Circuits/System

Other aspects of a CDIO-oriented Curriculum change

• In front of a conventional EE curriculum which provides common knowledge and competences for an average student profile, diversity in profiles should be considered attending to the various student interests and talents.

• This approach can be extended to the CDIO skills. A learning context for CDIO skill diversity exposes students to all four skills but can emphasize a given skill to a particular student. Specialization is then at technical and at skill levels

• A given student could master CDIO in antennas, CDIO in RF transceiver circuits or CDIO in microprocessor circuits.
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Case example: CDIO in Electrical Engineering at UPC

Comparison of skills provided by different frameworks

CDIO Syllabus

1 TECHNICAL KNOWLEDGE AND REASONING
   1.1. KNOWLEDGE OF UNDERLYING SCIENCES
   1.2. CORE ENGINEERING FUNDAMENTAL KNOWLEDGE
   1.3. ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE

2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES
   2.1. ENGINEERING REASONING AND PROBLEM SOLVING
   2.2. EXPERIMENTATION AND KNOWLEDGE DISCOVERY
   2.3. SYSTEM THINKING
   2.4. PERSONAL SKILLS AND ATTITUDES
   2.5. PROFESSIONAL SKILLS AND ATTITUDES

3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION
   3.1. TEAMWORK
   3.2. COMMUNICATION
   3.3. COMMUNICATION IN FOREIGN LANGUAGES

4 CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE AND SOCIETAL CONTEXT
   4.1. EXTERNAL AND SOCIETAL CONTEXT
   4.2. ENTERPRISE AND BUSINESS CONTEXT
   4.3. CONCEIVING AND ENGINEERING SYSTEMS
   4.4. DESIGNING
   4.5. IMPLEMENTING
   4.6. OPERATING

• 70 items at level 3
Case example: CDIO in Electrical Engineering at UPC

Comparison of skills provided by different frameworks

Selected skills

Generic skills mandatory at University
1. Innovation and entrepreneurship (CDIO 4.2)
2. Societal and environmental context (CDIO 4.1)
3. Communication in a foreign language (CDIO 3.3)
4. Oral and written communication (CDIO 3.2)
5. Teamwork (CDIO 3.1)
6. Survey of information resources (CDIO 2.2.2)
7. Autonomous learning (CDIO 2.4.6)

Additional skills at School level
1. Ability to identify, formulate and solve engineering problems (CDIO 2.1 - 2.3)
2. Ability to conceive, design, implement and operate complex systems in the field of ICT (CDIO 4.3 - 4.6)
3. Experimentation and knowledge of instrumentation (CDIO 2.2)
Case example: CDIO in Electrical Engineering at UPC

Curriculum architecture: Integrated project courses

Case example: CDIO in Electrical Engineering at UPC

Curriculum implementation

- Generic skills are embedded in all courses (2 per course)
- Specific design courses developed through multiple-impact activities

Introduction to EE (2nd semester)
  - Topics: System view. Project management
  - Seminars: oral and written communication, sustainability
  - Guided project (small groups 3-4)

- Engineering Project (4th)
  - Medium complexity
  - Medium size groups (5-6)

- Advanced Engineering Project (6th)
  - Complex, multidisciplinary
  - Large groups (9-12)

- Thesis (8th)
  - Individual

- Foster active learning methodologies
Skill itineraries

- Skill pathways defined by involving all courses.
- Every course may contribute to the learning of several of the ten skills at a given level (basic, medium, advanced) and should actively contribute to develop and assess two of them.
- In accordance with various frameworks, and in particular the CDIO initiative proposes to build an integrated curriculum with the skills embedded in the courses.

Case example: CDIO in Electrical Engineering at UPC

**Introduction to ICT Engineering course (I)**

<table>
<thead>
<tr>
<th>Week</th>
<th>Track 1 1h/week</th>
<th>Track 2 2 h/week</th>
<th>Track 3 2/h week (split group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lectures on system view cases</td>
<td>Course introduction</td>
<td>Basic system building</td>
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<tr>
<td></td>
<td>- Background</td>
<td>Information gathering</td>
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<td></td>
<td>- Need of the product</td>
<td>Introduction to project management</td>
<td></td>
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<tr>
<td></td>
<td>- System structure</td>
<td>SWOT and Brainstorming</td>
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<tr>
<td></td>
<td>- Involved technologies</td>
<td>Project management</td>
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<td></td>
<td></td>
<td>Measurement and acquisition circuits</td>
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<td></td>
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<td>ICT Business models</td>
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<tr>
<td></td>
<td></td>
<td>Cost determination</td>
<td>Data transmission and processing</td>
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<tr>
<td></td>
<td>- Abridged history</td>
<td>Marketing</td>
<td></td>
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<tr>
<td></td>
<td>- Business model</td>
<td>Sustainability and social commitment</td>
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<tr>
<td></td>
<td>- Societal implications</td>
<td>Finishing</td>
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<td></td>
<td>Seminar on oral and written communication</td>
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<tr>
<td>9</td>
<td>Seminar on intellectual and industrial property</td>
<td>investments</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Students presentations on system view</td>
<td>Marketing</td>
<td></td>
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<tr>
<td>11</td>
<td></td>
<td>Sustainability and social commitment</td>
<td></td>
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<tr>
<td>12</td>
<td></td>
<td>Finishing</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Students presentations on business ideas</td>
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</tbody>
</table>
Introduction to ICT Engineering course (II)

What do these systems have in common?

Introduction to ICT Engineering course (III)

Course Implementation. Design-Build project

- Underwater robot/vehicle construction: 3 weeks
  - Team creation
  - Basic project management concepts

- Payload construction: 9 weeks
  - This year: 3D traveled path reconstruction through a pressure sensor (depth) and a compass sensor (turns)
Introduction to ICT Engineering course (IV)

**Course Implementation. Design-Build project**
- Payload: 1st year: measurement of Temperature (depth)
- 2nd year: compass sensor and path reconstruction

Several concepts involved:
- Dynamic range coupling (sensor, amplifier, A/D)
- Errors, calibration
- Need of transmission protocols

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Conclusions

- In the current context of debating which transversal competences and skills should be acquired by EE students and the related methodologies to induce their learning, it is discussed in this work that beyond core technical skills (as conventionally included in Engineering Colleges) and soft skills (as more recently demanded by Society and companies), the competences of Conceiving, Design, Implementing and Operating Circuits and Systems are key for a comprehensive electrical engineering education.

- Methodologies to foster the active learning of such CDIO engineering competences are revisited and discussed.

- For a particular curriculum at our University, the description of learning activities and methodologies oriented to expose the student to such skills is described both at a curriculum architecture level as well as at course level, in the framework of the CDIO approach, an engineering education methodology which considers design-oriented analysis methods included in an integral project-based learning methodology.

- Emphasis is put in multiple-impact CDIO courses to foster acquisition of engineering competences, orbiting about the pivotal role of design, while also consolidating more conventional technical contents.