Competency-Based Learning in Mechanical Engineering at EPFL
Outline

- Introduction
- Project implementation
  - 1st phase: Determination of societal needs and macro-competencies
  - 2nd phase: Formulation of learning outcomes
  - 3rd phase: Implementation in the curriculum
- Lessons learned
Introduction – Why?

- Bologna and international accreditation trends
  - Continuous quality improvement
  - Learning outcomes integration
  - European Qualification Framework (EQF)

- OAQ-CTI audit recommendations
  - Better description of targeted competences
  - Curricula more industry-oriented
  - More project/hands-on activities at the bachelor level

- Why Mechanical Engineering?
  - Pilot project before extending to whole EPFL
  - Laboratory (LGPP) with experience in competency-based approaches in the industrial environment
Introduction – The Objectives

To establish a framework and process for piloting the Bachelor and Master programs

- Reference on knowledge and skills that students must have at a given level
- Tool to help students in the choice of courses
- Framework to help teachers coordinate and relate different courses
- “Curriculum-pertinence” criterion for the introduction and suppression of subjects
Project implementation – 1st phase

- Determine societal needs for EPFL mechanical engineers (Delphi poll)
- List of required macro-competencies (CTI approach)

Delphi panel
Industrial advisory board
Pedagogists
Project implementation – 1\textsuperscript{st} phase

Composition of the Delphi panel:

- 37 out of 52 completed questionnaires
- 10 women, 42 men
- Alma mater: 32 EPFL
- Background: 25 Mechanical engineering
- Degree: 12 PhD, 21 Master
- Work experience: 4 <5 years, 9 5 to 10 years, 25 >10 years
- Position: 12 R&D, 11 Management, 5 Production
- Company’s size: 12 SME, 27 LE
- Company’s business: 25 manufacturing, 3 energy distribution, 3 transportation, 2 car manufacturer
## Project implementation – 1st phase

### A.2 Savoir en sciences de l’ingénieur

La formation polytechnique de Génie mécanique conduit à des projets fortement différents. Parmi les branches essentielles ci-dessous, choisissez une partie du savoir solide acquis par tout ingénieur issu de la section et indiquez le niveau d’approfondissement que doit avoir atteint le diplôme à : 1 = savoir et comprendre ; 2 = appliquer et analyser ; 3 = évaluer et créer.

<table>
<thead>
<tr>
<th>Sélection de 5 branches essentielles</th>
<th>Approfondissement nécessaire</th>
</tr>
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<tbody>
<tr>
<td>❑ 1 2 3 (a) Mécanique vibratoire</td>
<td>(a) Techniques de mesure</td>
</tr>
<tr>
<td>❑ 1 2 3 (b) Dynamique des fluides</td>
<td>(b) Planification et conduite d’expériences</td>
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<tr>
<td>❑ 1 2 3 (c) Thermodynamique</td>
<td>(c) Méthodologie de programmation</td>
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<td>❑ 1 2 3 (d) Mécanique des milieux continus</td>
<td>(d) Maîtrise de langages spécifiques de programmation</td>
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<tr>
<td>❑ 1 2 3 (e) Automatique</td>
<td>(e) Techniques de simulation</td>
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<tr>
<td>❑ 1 2 3 (f) Mécatronique</td>
<td>(f) Maîtrise de logiciels spécifiques de simulation</td>
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<tr>
<td>❑ 1 2 3 (g) Conception mécanique</td>
<td>(g) Méthodologie de résolution de problèmes</td>
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<tr>
<td>❑ 1 2 3 (h) Matériaux</td>
<td>(h) Gestion et conduite de projets individuels</td>
</tr>
<tr>
<td>❑ 1 2 3 (i) Optimisation</td>
<td>(i) Gestion et conduite de projets collaboratifs</td>
</tr>
<tr>
<td>❑ 1 2 3 (j) Electronique</td>
<td>(j) Méthodologie et principes de modélisation et de calcul numérique</td>
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<tr>
<td>❑ 1 2 3 (k) Autre :</td>
<td>(k) Maîtrise de logiciels spécifiques de modélisation et de calcul</td>
</tr>
<tr>
<td>❑ 1 2 3 (l) Autre :</td>
<td>(l) Méthodologie de conception</td>
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<tr>
<td>❑ 1 2 3 (m) Autre :</td>
<td>(m) Maîtrise d’outils spécifiques de CAD-CAM</td>
</tr>
<tr>
<td>❑ 1 2 3 (n) Autre :</td>
<td>(n) Méthodes du Systems Engineering</td>
</tr>
<tr>
<td>❑ 1 2 3 (o) Autre :</td>
<td>(o) Techniques de présentation orale</td>
</tr>
<tr>
<td>❑ 1 2 3 (p) Autre :</td>
<td>(p) Techniques de présentation écrite</td>
</tr>
<tr>
<td>❑ 1 2 3 (q) Autre :</td>
<td>(q) Techniques de recherche documentaire (littératures, brevets, specs, …)</td>
</tr>
<tr>
<td>❑ 1 2 3 (r) Autre :</td>
<td>(r) Autre :</td>
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<tr>
<td>❑ 1 2 3 (s) Autre :</td>
<td>(s) Autre :</td>
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<tr>
<td>❑ 1 2 3 (t) Autre :</td>
<td>(t) Autre :</td>
</tr>
</tbody>
</table>

### B.1 Savoir-faire

Quantifier l’importance des savoir-faire suivants :

1 = sans importance ; 2 = désiré ; 3 = prioritaire ; 4 = essentiel au niveau Master

| (a) Techniques de mesure     | 1 2 3 4 |
| (b) Planification et conduite d’expériences | 1 2 3 4 |
| (c) Méthodologie de programmation | 1 2 3 4 |
| (d) Maîtrise de langages spécifiques de programmation | 1 2 3 4 |
| (e) Techniques de simulation | 1 2 3 4 |
| (f) Maîtrise de logiciels spécifiques de simulation | 1 2 3 4 |
| (g) Méthodologie de résolution de problèmes | 1 2 3 4 |
| (h) Gestion et conduite de projets individuels | 1 2 3 4 |
| (i) Gestion et conduite de projets collaboratifs | 1 2 3 4 |
| (j) Méthodologie et principes de modélisation et de calcul numérique | 1 2 3 4 |
| (k) Maîtrise de logiciels spécifiques de modélisation et de calcul | 1 2 3 4 |
| (l) Méthodologie de conception | 1 2 3 4 |
| (m) Maîtrise d’outils spécifiques de CAD-CAM | 1 2 3 4 |
| (n) Méthodes du Systems Engineering | 1 2 3 4 |
| (o) Techniques de présentation orale | 1 2 3 4 |
| (p) Techniques de présentation écrite | 1 2 3 4 |
| (q) Techniques de recherche documentaire (littératures, brevets, specs, …) | 1 2 3 4 |
| (r) Autre : | 1 2 3 4 |
| (s) Autre : | 1 2 3 4 |
| (t) Autre : | 1 2 3 4 |
Project implementation – 1\textsuperscript{st} phase

Knowledge of Engineering Subjects

- Mechanical design
- Thermodynamics
- Materials
- Mechanical vibrations
- Fluid dynamics
- Control
- Optimisation
- Continuum mechanics
- Mechatronics
- Other 1
- Other 2
- Electronique

Legend:
- Not specified
- Know and understand
- Apply and analyse
- Assess and create
Project implementation – 1st phase

Knowledge of Engineering-Related Subjects

- English: Essential at Master level
- Communication: Essential at Master level
- Economy: Very Important
- German: Important
- Marketing: Very Important
- Human Resources: Important
- Accounting: Very Important
- Law: Essential at Master level
- Finance: Important

Competency-Based Learning in Mechanical Engineering at EPFL
Project implementation – 1st phase

Required macro-competencies

**Competency 1**: Understand, quickly adapt to and communicate with the professional, technological, natural and economical environment

**Competency 2**: Identify, model, and analyze problems from a complex reality by adopting a scientific, holistic and multidisciplinary approach

**Competency 3**: Design and implement innovative, effective and durable solutions in an industrial and/or research context

**Competency 4**: Manage people and projects

**Competency 5**: Act professionally and responsibly
Project implementation – 2\textsuperscript{nd} phase

From competencies to learning outcomes for the 6 concentrations and the transversal domain

Teaching Commission
Concentration Advisors and Teachers
Pedagogists
Project implementation – 2nd phase

Competency-Based Learning in Mechanical Engineering at EPFL

Solids & Structures
Biomechanics
Aero-Hydrodynamics
Design & Production
Energy
Control & Mechatronics

6 Concentrations
Examples of Learning Outcomes

- **Energy:**
  - Master the concepts of mass, energy, and momentum balance, E1
  - Design a measurement set-up for an energy conversion system, E27

- **Aero-Hydrodynamics:**
  - Link flow behaviour with non-dimensional parameters (e.g. Reynolds and Mach numbers), AH2
  - Optimize the behaviour of a given flow by a numerical or experimental approach, AH38

- **Transversal Domain:**
  - Write a scientific or technical report, T6
  - Form and motivate a team, T13
Project implementation – 3rd phase

- Modifications of the curriculum
- New course description

- Database of competencies
- Student orientation tool
- 2nd round of modifications of the curriculum

Teaching Commission
Concentration Advisors
Industrial advisory board
Project implementation – 3rd phase

Modifications of the curriculum

- Revamped courses
  - “Computer-aided engineering I, II” become “Introduction to programming” and “Introduction to algorithmics”, taught by a teacher in Mechanical engineering (1st year)
  - Statics becomes Mechanics of structures I and is better coordinated with Mechanics of structures II, formerly Mechanics of structures (1st, 2nd year)
  - Fusion of Production processes and Metals forming in one course (2nd year)
  - Finite difference and finite volume methods become Discretization methods (3rd year)
Project implementation – 3rd phase

Modifications of the curriculum

- New courses
  - Introduction to mechanical engineering (1st year)
  - Fluid flow (2nd year)
  - Aeroelasticity and fluid-structure interaction (Master)
  - Particle-based methods (Master)
  - Mandatory Engineering internship (Master)

- Other modifications
  - Electronics from 2nd to 3rd year
  - Elimination of redundancies in the Design & Production concentration
**Learning outcomes:**

**Domain skills:**
- Master the concepts of thermodynamic efficiency, E6
- Establish the flow diagram of an industrial process and calculate the corresponding energy and mass balance, E22
- Analyse the energy and exergy efficiency of industrial energy systems, E23
- Know the principles and limitations of the main energy conversion technologies, E7
- Understand the challenges related to energy: resources, energy services, economic and environmental impacts, E9

**Transversal skills:**
- Write a scientific or technical report, T6
- Make an oral presentation, T7
- Document and communicate a project, T12
- Analyse the consequences of a decision or solution, T20

**Required prior knowledge:**
- Master the concepts of mass, energy, and momentum balance, E1 (Thermodynamique et énergétique I)
- Compute the thermodynamic properties of a fluid, E2 (Thermodynamique et énergétique I)
- Master the concepts of heat and mass transfer, E3 (Heat and mass transfer)
- Understand the main thermodynamic cycles, E5 (Thermodynamique et énergétique I)
- Calculate and design heat exchangers, E15 (heat and mass transfer)
- Notion of optimization (Introduction à l'optimisation différentiable)

**Keywords:**
Energy efficiency, heat recovery, Energy conversion, Exergy analysis, Pinch analysis, Industrial processes

**Required prior knowledge:**
- Master the concepts of mass, energy, and momentum balance, E1 (Thermodynamique et énergétique I)
- Compute the thermodynamic properties of a fluid, E2 (Thermodynamique et énergétique I)
- Master the concepts of heat and mass transfer, E3 (Heat and mass transfer)
- Understand the main thermodynamic cycles, E5 (Thermodynamique et énergétique I)
- Calculate and design heat exchangers, E15 (heat and mass transfer)
- Notion of optimization (Introduction à l'optimisation différentiable)
Project implementation – 3rd phase

Next steps:

- Database of competencies
- Student orientation tool
- 2nd round of modifications of the curriculum
Lessons learned

Errors & Difficulties

- Delphi questionnaire
- Non-uniformity of the formulation of learning outcomes
- Time-management
- Communication of the project
- Actual feasibility of modifications of the curriculum (constraints, personnel, facilities)