IMPROVING TEACHING EFFECTIVENESS IN CHEMICAL ENGINEERING EDUCATION

J. Glassey¹, E. Schaer², A. Porjazoska Kujundziski³, V. Meshko³, L. M. Madeira⁴, M. Polakovic⁵, N. Kockmann⁶

¹Newcastle University, Newcastle upon Tyne, United Kingdom,
²Université de Lorraine, UL Nancy, France,
³International Balkan University (IBU),
⁴Faculdade de Engenharia da Universidade do Porto, Porto, Portugal,
⁵Slovak Technical University, Bratislava, Slovakia,
⁶TU Dortmund University, BCI, Dortmund, Germany
Project aim

Develop a framework which will support the assessment of teaching effectiveness in delivering not only core chemical engineering knowledge, but also core employability competencies in a range of geographical and educational context.

More detail on www.iteach-chemeng.eu
Consortium partners

16 associate partners formally signed up, representing professional institutions, employers, HEIs.
PROJECT OBJECTIVES

1. Review the learning outcomes of a chemical engineering education.
2. Promote closer involvement of employer organisations in chemical engineering curriculum formation by carrying out focus groups.
3. Establish state-of-the-art in assessing the effectiveness of teaching of core chemical engineering knowledge.
4. Define various indicators of the effectiveness of teaching in chemical engineering higher education.
5. Investigate in more depth methods of effectively acquiring employability competencies.
6. Use decision making technology and multi-objective optimisation to identify the most appropriate evaluation methods.
7. Test the framework at partner institutions focusing on various pedagogic methodologies.

XXIV CONGRESS OF CHEMISTS AND TECHNOLOGISTS OF MACEDONIA
Project overview

WP1 Management  Oct ‘13 - Sep ‘16

WP2 Data gathering  Jan ’14 - Dec ‘14

WP3 Assessment framework  Jan ‘15 - Aug ‘15

WP4 Pilot implementation  May ‘15 - Sep ‘16

WP5 Quality Assurance  Oct ‘13 - Sep ‘16

WP6 Dissemination  Jan ‘14 - Sep ‘16

WP7 Exploitation  Jan ‘14 - Sep ‘16
WP2 : DATA COLLECTION

Gathering information on the current state-of-the-art in measuring effectiveness of teaching and perceptions from academics, employers and recent graduates.

Questionnaires

The surveys contained within this section of the website are designed to assess whether, and to what extent, intended university learning outcomes are relevant post-graduation.

The questionnaire is divided into 5 sections:

(1) Underpinning Mathematics and Science
(2) Core Chemical Engineering Knowledge
(3) Engineering Practice and Design
(4) Advanced level
(5) Embedded Learning
WP 2: Data analysis methodology

Quantitative statistical data analysis

✓ Measures of central tendency (M, SD, Min, Max) and frequency counts were calculated for all Likert-scale type questions.

✓ Frequency counts were conducted for single-choice answers.

✓ Group comparison was carried out after classifying the responses geographically using United Nations Geoscheme for Europe, created by the UN Statistics Division

http://millenniumindicators.un.org/unsd/methods/m49/m49regin.htm

✓ Independent-samples t-tests conducted for all Likert-scale type questions - differences between geographical regions, position and company size.

➢ Multivariate Data Analysis (MVDA) methods.
WP2: Data analysis methodology

Qualitative data
Focus group - semi-structured interviews

✓ Responses (free text) to questions have been analysed by NVivo software
  Identified a number of predominant themes/patterns and frequencies of occurrence in each questionnaire

✓ Carried out on the results of focus group interviews.
What is your institution's predominant method of teaching each of these competencies? - ACADEMICS
Methods of delivery (Advanced level) - ACADEMICS
From your experience as a student, what was the predominant method of teaching for each competency? - GRADUATES
Overall, how effective were the methods of teaching that you experienced on your course? - GRADUATES

- Lectures:
  - Very ineffective: 11.1%
  - Ineffective: 11.8%
  - Neutral: 9.5%
  - Effective: 33.3%
  - Very Effective: 46%

- Labs:
  - Very ineffective: 1.6%
  - Ineffective: 9.8%
  - Neutral: 37.7%
  - Effective: 50.8%

- Tutorials:
  - Very ineffective: 18.2%
  - Ineffective: 14.5%
  - Neutral: 1.8%
  - Effective: 65.5%

- Case Studies:
  - Very ineffective: 0%
  - Ineffective: 0%
  - Neutral: 12.3%
  - Effective: 38.6%
  - Very Effective: 49.1%

- Problem-based:
  - Very ineffective: 0%
  - Ineffective: 0%
  - Neutral: 5.2%
  - Effective: 36.2%
  - Very Effective: 58.6%
How important do you consider each of these competencies for your career - GRADUATES

Fig. 8. Employability Competencies - Graduates

How important do you consider the following graduate attributes for your business? - EMPLOYERS

Fig. 9. Employability Competencies – Employers
WP2: Qualitative data
Focus group - semi-structured interviews
Academics

Current methods of assessing the effectiveness of delivery in academia:

• Performance of students in examinations
• Use of satisfaction surveys
• Peer observation
• Accreditation visits
• National employment statistics of graduates

Effectiveness of delivering employability competencies

• Students performance in assessment tasks
• Project and lab reports
• Student satisfaction surveys
• Oral presentations
• Feedback from external contributors
• No specific methods
Employers

Assess the competencies of graduates:

- No significantly predominant methods
- CV and references
- Assessment centres and interviews
- Company specific pro-forma tasks
- Probation period

Graduates

Effective methods:

- Lectures – most of the answers
- Problem based
- Case study
WP 3: Assessment framework

>160 parameters; 7 Indicators

Industry/Education

Inlet/raw materials

1. Attractiveness
2. Pedagogy
3. Quality of management

Outlet/Products

Students

4. Learning outcomes
5. Relation with industry
6. Relation with research
7. Employment

Engineers
EVALUATION OF A WHOLE FORMATION

Quantification of each parameter

Example for Pedagogy

<table>
<thead>
<tr>
<th>Teaching</th>
<th>Mean value</th>
<th>Standard Deviation</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours (or ECTS) of classical lectures</td>
<td>100</td>
<td>30</td>
<td>$e = 12 \exp \left( \frac{V - \mu}{\sigma} \right)^2$</td>
</tr>
<tr>
<td>Hours (or ECTS) of tutorials</td>
<td>50</td>
<td>30</td>
<td>$e = 12 \exp \left( \frac{V - \mu}{\sigma} \right)^2$</td>
</tr>
<tr>
<td>Hours (ECTS) of labs</td>
<td>50</td>
<td>30</td>
<td>$e = 12 \exp \left( \frac{V - \mu}{\sigma} \right)^2$</td>
</tr>
<tr>
<td>Hours (ECTS) of Problem &amp; Project Based Learnings</td>
<td>50</td>
<td>30</td>
<td>$e = 12 \exp \left( \frac{V - \mu}{\sigma} \right)^2$</td>
</tr>
<tr>
<td>Hours (ECTS) of NTICs</td>
<td>50</td>
<td>30</td>
<td>$e = 12 \exp \left( \frac{V - \mu}{\sigma} \right)^2$</td>
</tr>
</tbody>
</table>

Maximum score for teaching : 60

- $e$ - effectiveness,
- $V$ - the value of ECTS for a given teaching method,
- $\mu$ - the average value and
- $\sigma$ - the standard deviation

Score of each indicator (on 300) divided by the cost of formation, related to the national average salary.
**EVALUATION OF A SINGLE MODULE**

Framework metrics for individual unit/course

<table>
<thead>
<tr>
<th>Metric</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Strategic nature of the course/discipline</td>
<td>( M1 = \frac{2A + G + 2E}{5} )</td>
</tr>
<tr>
<td>2. Relevance of the proposed formation</td>
<td>( M2 = \frac{2A + G + E + S}{5} )</td>
</tr>
<tr>
<td>3. Pedagogical relevance of the teaching approach</td>
<td>( M3 = \frac{2A + 2G + S}{5} )</td>
</tr>
<tr>
<td>4. Perception of relevance of the pedagogical approach</td>
<td>( M4 = S )</td>
</tr>
<tr>
<td>5. Evaluation of the acquisitions</td>
<td>----</td>
</tr>
<tr>
<td>6. Evaluation of transfer</td>
<td>( M6 = \frac{A + 2G + 2E}{5} )</td>
</tr>
</tbody>
</table>

**Diagram:**

- **Pedagogical objectives**
  - Delivered knowledge (what is taught)
  - Acquired knowledge (validated in professional situation)
  - Used knowledge (what is known and used before the formation)
  - Applied knowledge (ability to do after the formation)

- **Performance objectives**
  - Competencies after the formation. The horizontal axis shows the actual use of UO in professional situations.

- **Operational objectives**
  - Transferring of knowledge objectives
Proposed pedagogical approaches

P1 (UNEW) – recorded lectures, problem based learning

P2 (UL) – problem based learning, self-instruction delivery

P3 (IBU) – work-based learning, traditional lectures

P4 (FEUP) – recorded lectures, practical instruction via labs

P5 (STU) – traditional lectures, practical instruction via labs

P6 (TUDO) - work-based learning, problem based learning

A common course chosen - Reaction Engineering
Chemical Reaction Engineering (1\textsuperscript{st} Semester)

1. Strategic nature of the course/discipline
2. Relevance of the proposed formation
3. Pedagogical relevance of the teaching approach
4. Perception of relevance of the pedagogical approach
5. Evaluation of transfer
6. Evaluation of transfer

Portugal
Macedonia
Slovakia
France
United Kingdom
WP4: PILOT IMPLEMENTATION - RESULTS

Reaction Engineering (1st semester);
Metric: 1. Strategic nature of the course/discipline

Academics
Graduates
Employers
Students

Grade

IBU (Macedonia) - traditional lectures
Newcastle (UK) - recorded lectures
STU (Slovakia) - practical instruction via labs
TU Dortmund (Germany) - Traditional Lectures
Univ. Lorraine (France) - traditional lectures
FEUP (Portugal) - recorded lectures
PILOT IMPLEMENTATION - RESULTS

Reaction Engineering (1st semester);
Metric: 2. Relevance of the proposed formation

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Academics</td>
<td></td>
</tr>
<tr>
<td>Graduates</td>
<td></td>
</tr>
<tr>
<td>Employers</td>
<td></td>
</tr>
<tr>
<td>Students</td>
<td></td>
</tr>
</tbody>
</table>

- IBU (Macedonia) - traditional lectures
- Newcastle (UK) - recorded lectures
- STU (Slovakia) - practical instruction via labs
- TU Dortmund (Germany) - traditional Lectures
- Univ. Lorraine (France) - traditional lectures
- FEUP (Portugal) - recorded lectures
PILOT IMPLEMENTATION - RESULTS

Reaction Engineering (1st semester);
Metric: 3. Pedagogical relevance of the teaching approach

Academics | Graduates | Employers | Students
--- | --- | --- | ---
3.6 | 3.4 | 4.4 | 4.0

IBU (Macedonia) - traditional lectures
Newcastle (UK) - recorded lectures
STU (Slovakia) - practical instruction via labs
TU Dortmund (Germany) - traditional Lectures
Univ. Lorraine (France) - traditional lectures
FEUP (Portugal) - recorded lectures
PILOT IMPLEMENTATION - RESULTS

Reaction Engineering (1st semester);
Metric: 4. Perception of relevance of the pedagogical approach

Grade

IBU (Macedonia) - traditional lectures
Newcastle (UK) - recorded lectures
STU (Slovakia) - practical instruction via labs
TU Dortmund (Germany) - traditional Lectures
Univ. Lorraine (France) - traditional lectures
FEUP (Portugal) - recorded lectures
PILOT IMPLEMENTATION - RESULTS

Reaction Engineering (1st semester);
Metric: 6. Evaluation of transfer

Academics
Graduates
Employers
Students

Grade

Stakeholder

IBU (Macedonia) - traditional lectures
Newcastle (UK) - recorded lectures
STU (Slovakia) - practical instruction via labs
TU Dortmund (Germany) - traditional Lectures
Univ. Lorraine (France) - traditional lectures
FEUP (Portugal) - recorded lectures
Proposal for Metric 5 - Evaluation of the acquisitions

Deals with the acquisitions of students during and after the course, including regular evaluations;

Proposals for the mark in a given course, in academic year $y$:

$M5 = \frac{\left(\frac{AM_{y}}{AM_{y-1}}\right)_{\text{course}}}{\left(\frac{AM_{y}}{AM_{y-1}}\right)_{\text{cohort}}} \times 3$

$M5' = \frac{\left(\frac{AM_{y}}{AM_{y-1}}\right)_{\text{course}}}{\left(\frac{AM_{y}}{AM_{y-1}}\right)_{\text{cohort}}} \times 1.5 + \frac{\left(\frac{STD_{y}}{STD_{y-1}}\right)_{\text{cohort}}}{\left(\frac{STD_{y}}{STD_{y-1}}\right)_{\text{course}}} \times 1.5$

<table>
<thead>
<tr>
<th>Partner</th>
<th>Metric</th>
<th>2013/14</th>
<th>2014/15</th>
<th>2015/16</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCL</td>
<td>M5</td>
<td>2.4</td>
<td>3.2</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>M5'</td>
<td>2.7</td>
<td>3.1</td>
<td>2.8</td>
</tr>
<tr>
<td>UL</td>
<td>M5</td>
<td>2.3</td>
<td>2.4</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td>M5'</td>
<td>2.7</td>
<td>2.7</td>
<td>3.5</td>
</tr>
</tbody>
</table>

- Variations along time not so clear!...
Refinement of Metric 5

\[ M_5 = \left( \frac{AM_y^{course}}{AM_{y-1;y-3}^{course}} \right) \times 3 \]

\[ M_5' = \left( \frac{AM_y^{course}}{AM_{y-1;y-3}^{course}} \right) \times 1.5 + \left( \frac{STD_y^{cohort}}{STD_{y-1;y-3}^{cohort}} \right) \times 1.5 \]

AM – average mark
STD – standard deviation of the marks

### Partner | Metric | 2015/16
--- | --- | ---
NCL | M5 | 2.5
 | M5’ | 2.8
UL | M5 | 3.1
 | M5’ | 3.1

- Metric definition is independent of local grading scale!
CONCLUSIONS

• Two frameworks for the assessment of teaching effectiveness have been developed.
• The first one is related to the effectiveness of a whole formation.
• The second one is assigned to a single teaching unit.
• Although the focus of this project is oriented toward chemical engineering formation, the concepts and approaches could be applied to other areas of higher education.
THANK YOU
for your attention

http://www.iteach-chemeng.eu
Framework metrics for individual unit/course

1. Strategic nature of the course for required knowledge and competencies
   - Analysis of the needs made by pedagogical team or steering committee,
   - Prospective approach (evolution of the needs, national and international labor markets, evolution of the students’ culture, etc.)
   - Comparison with other competing courses; Benchmarking
   - Capacity of adaptation of the specialized formation (flexibility of the teachers, new technologies, organizational changes)
   - Reflecting about how this course fits into the attractiveness of the formation vis-à-vis of future students
Framework metrics for individual unit/course

2. Relevance of the proposed formation

- The content of the teaching unit is adequate,
- Its position in the program is adapted,
- Its duration is adapted,
- Its level is adapted
- It is described according to clear learning outcomes,
- Its relations (or prerequisites) with other teaching units are appropriate,
- It allows accessing the four levels of taxonomy (knowledge, comprehension, application, analysis)
Framework metrics for individual unit/course

3. Pedagogical relevance of the specific approach within the course
   - To report a progression; Evaluation of the acquisitions
   - Definition in terms of learning outcomes,
   - The mobilized resources (social and cognitive skills)
   - The available resources
   - The document and the progression
   - The level of autonomy
   - The integration of individual differences
Framework metrics for individual unit/course

4. Student perception of the pedagogical approach tested

- Assessment of the quality of the course of formation: of some parts or of the entire course;
- Understanding the relevance of the topic for my future profession
- Clarity of teaching unit objectives
- Education level required
- Broadness
- Time allowed
- Teaching methods implemented
- Relevance of the links with other taught subjects
Framework metrics for individual unit/course

5. Relevance of the pedagogical approach in supporting internalization of knowledge for professional capacity (capturing vertical dimension of slides 32, 33, delivered vs internalized knowledge)

- Estimation of the importance of the course if the student had followed all the other courses, except this one in particular.
- Links of the formation with the reality of the field (if this is possible)
- Faculty of transfer during practical work; during industrial internships (including expected feedback from the students):
  - How much of your formation has been useful during this internship?
  - Which parts do you consider useful for the future?
  - Which parts do you consider unnecessary?
Framework metrics for individual unit/course

6. Employer evaluation of knowledge/skills acquired - capturing the horizontal dimension: acquired vs subconscious or used knowledge.

- Control of concepts,
- Ability to extend the concepts to new problems,
- Knowledge and understanding,
- Engineering analysis and design,
- Investigations and practice,
- Ability to do research, to participate in innovation
- Transferable skills
EVALUATION OF A SINGLE MODULES

Metric 2: Relevance of the proposed formation

- It allows accessing the four levels of knowledge taxonomy (knowledge, comprehension, application and analysis)
  - Traditional Lectures: $M_2 = 4.1$
  - PBL: $M_2 = 4.0$
  - Self Delivery: $M_2 = 4.0$

- Its relations (or prerequisites) with other teaching units (courses) are appropriate

- Appropriate learning outcomes are clearly formulated for this teaching unit (course)

- Its duration / workload / ECTS is appropriate

- Its position in the overall program is appropriate

- The content of the teaching unit (course) is adequate
Metric 3: Pedagogical Relevance of the teaching approach

- I learned something which I consider valuable
- My interest in the subject has increased as a consequence of this course
- The teaching unit (course) is dynamic and enthusiastic
- The course is intellectually challenging and stimulating
- Teacher’s explanations were clear
- The proposed pedagogy enables appraising the progression
- The proposed pedagogy enables working in professional situation
- The proposed pedagogy (e.g. labs, tutorials, projects, works, multimedia documents (if present)) improve the...
- The pedagogy improves skills and competencies
- The proposed pedagogy promotes active learning
- The proposed pedagogy is appropriate to different students’ learning styles
- The proposed pedagogy allows accessing different levels of knowledge taxonomy
- The proposed formation and pedagogy is appropriate to the learning outcomes
EVALUATION OF DIFFERENT MODULES

Metric 3: Pedagogical Relevance of the teaching approach

- Traditional lectures
- PBL
- Self Delivery

<table>
<thead>
<tr>
<th>Metric</th>
<th>Module 3</th>
<th>Module 4</th>
<th>Module 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>If you needed some explanations you would?</td>
<td>3.7</td>
<td>4.0</td>
<td>3.9</td>
</tr>
<tr>
<td>I was able to appraise my progression</td>
<td>3.7</td>
<td>4.0</td>
<td>3.9</td>
</tr>
<tr>
<td>The mark you obtained (if already available) reflects my level and effort</td>
<td>3.7</td>
<td>4.0</td>
<td>3.9</td>
</tr>
<tr>
<td>Feedback on examinations/graded materials was valuable</td>
<td>3.7</td>
<td>4.0</td>
<td>3.9</td>
</tr>
<tr>
<td>Methods of evaluating student work were fair and appropriate</td>
<td>3.7</td>
<td>4.0</td>
<td>3.9</td>
</tr>
<tr>
<td>Further reading, homework, laboratories (if applicable) contributed to the appreciation and understanding of the...</td>
<td>3.7</td>
<td>4.0</td>
<td>3.9</td>
</tr>
<tr>
<td>I understand the relevance of the topic for my future profession</td>
<td>3.7</td>
<td>4.0</td>
<td>3.9</td>
</tr>
<tr>
<td>The balance between classical and active learning was adequate</td>
<td>3.7</td>
<td>4.0</td>
<td>3.9</td>
</tr>
<tr>
<td>Proposed objectives agreed with those actually taught, so you knew where the course was going</td>
<td>3.7</td>
<td>4.0</td>
<td>3.9</td>
</tr>
<tr>
<td>The breadth of the teaching unit (course) was appropriate</td>
<td>3.7</td>
<td>4.0</td>
<td>3.9</td>
</tr>
<tr>
<td>Group interactions were encouraged</td>
<td>3.7</td>
<td>4.0</td>
<td>3.9</td>
</tr>
</tbody>
</table>
**EVALUATION OF DIFFERENT MODULES**

**Metric 4: Relevance of the proposed formation**

The project helped me to understand and deepen some points of the course

The rhythm was appropriate

The multimedia/monitoring helped me to understand some points of the project

Teacher’s explanations were clear

The quality of the materials (e.g. videos, ...) and documents was appropriate

Course materials were well prepared and carefully explained

The proposed pedagogical approach improved my interest in the subject

- **M₄ = 4.1**
- **M₃ = 4.1**
- **M₃ = 4.1**
Metric 5: Evaluation of acquisitions

Average marks

Standard deviations