Lifelong Learning Programme

Improving Teaching Effectiveness in Chemical Engineering Education

ITEACH

Trends in current learning outcomes and criteria of effectiveness of delivery

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Contents

Executive summary

This report discusses the development of a robust and objective framework for the assessment of the effectiveness of delivering core chemical engineering knowledge and employment competencies. The outcomes of the extensive review of intended learning outcomes set by various national accreditation and governmental bodies are presented here, indicating a very consistent approach across Europe and worldwide. A detailed methodology for collecting responses from all three stakeholder groups (academics, employers and graduates) on the importance of various areas of CE knowledge and employment competencies, current methods of delivering these as well as the current methods of assessing the effectiveness of their delivery is also described. The analysis, including univariate and multivariate statistical analysis of numerical responses and structured analysis of the free text responses, indicates very few differences in the perceptions of the importance of core knowledge and employment competencies within various geographical areas or company size.

The predominant current methods of evaluating the effectiveness in academic environment centre around examination performance and student satisfaction questionnaires with more project based assessment and presentations for the employability competencies. From the employer perspective, the assessment methods include CV and references, performance during the interview and assessment centres as well as 'on-the-job' performance during probation periods.

The analysis of the focus group transcripts re-enforced the initial findings of the questionnaires in terms of the importance of various areas of CE knowledge and employability competencies. It also indicated the concerns regarding the validity and the robustness of the current methods of assessing the effectiveness of delivery, although no specific suggestions for better means were introduced by the focus group participants. On the basis of the outcomes of these analyses, together with detailed literature review and, using engineering decision making tools, iTeach project work package 3 will propose a draft version of the assessment framework to be tested in pilot studies at partner institutions.

1. Introduction

The continuous evolution of the chemical engineering (CE) profession and, with it, that of the education, is widely recognised (e.g. Molzahn, 2004; IChemE, 2014). The changing technology needs of a global knowledge economy and the societal challenges we are facing demand increasingly more effective engineering education with far broader skills than simply the mastery of scientific and technological disciplines (Forum for Future, 2000). The engineers must have an understanding of people with different backgrounds and different cultural values and must be able to interact with them effectively. This places additional requirements on the educational systems. The educators at the universities have a tendency to place emphasis predominantly on the fundamental knowledge and research methodologies in their courses rather than practical experience and engineering practice (National Academy of Engineering, 2009). Thus a more extensive involvement of industrial experts in the curriculum design and delivery is required to ensure relevant competencies are developed. In addition, it is important that robust criteria of assessing the effectiveness of the core knowledge and competency delivery are implemented across the higher education sector to ensure the achievement of key aims of European education policies (National Academy of Engineering, 2009). Thus evaluating the effectiveness of teaching and competency development will enable the identification of the most effective ways of promoting these competencies and ultimately promote the improvement of their delivery.

A preliminary survey of the available pedagogical literature on measuring the effectiveness of pedagogical approaches in education has shown that most reports on assessing the effectiveness of teaching have been related to primary or secondary school teacher evaluation, not the higher education. Attempts to establish metrics for teaching effectiveness have assumed many forms but normally have focused on student responses to written questions. Despite some strong opposition to incorporating such student ratings in university evaluation, they are widely used. In the last two decades there have been some studies and projects (National Academy of Engineering, 2009) focused on establishing a system of measuring the effectiveness of teaching in higher education in engineering in general. Some studies concerning CE education have been performed (National Academy of Engineering, 2009). However a consistent and robust approach to assessing the effectiveness of various pedagogical methodologies, in particular those aimed at developing important core competencies related to employability of the graduates, is critical and long overdue, given that 'the competitiveness of the country and therefore our standard of living hinges on our ability to educate a large number of sufficiently innovative engineers' (Tryggvason and Apelian, 2014).

The European Chemistry and Chemical Engineering network (EC2E2N) [20] reviewed the CE higher education provision in 2006 and provided indicators of various pedagogical approaches, highlighting the importance of measuring their effectiveness and providing useful collection of material as a starting point for our work in this project. However, it is critical that a comprehensive trans-European project involving representatives of potential employers and professional bodies is undertaken and objective evaluation methods are used to construct a robust assessment framework for evaluating the effectiveness of delivery of core knowledge and employability competencies as proposed by this project.

2. Overview of learning outcomes

An extensive review of CE higher education learning outcomes from various professional bodies (e.g. IChemE, UK, AIChE, USA, Engineers Australia, Engineers Ireland) as well as national accreditation requirements of all partner/associate partner countries was carried out by researchers at Newcastle University (P1). It was noted that there was a high level of similarity between the various national/professional body requirements, particular in the area of core CE knowledge and major categories of professional skills and employability competencies. Any differences observed were mainly in the emphasis on specific areas of skills or additional areas of knowledge. The glossary of learning outcomes was constructed and published on the iTeach website (http://www.iteach-chemeng.eu/questionnaires/details/). This served as a basis for the questionnaires used to survey the opinions of all stakeholders – academics, employers and graduates (see section 3 for details of methodology).

3. Data collection methodology

3.1 Questionnaires

Separate questionnaires were developed for each of the stakeholder groups by Partner 1 (UNEW) researchers with expertise in pedagogical research and the use of questionnaires in such research. Each questionnaire (see Appendix 9.1) sought the views of the respondents both in terms of Lickert scale numerical responses and free text qualitative responses. Whilst there were common questions in each of the questionnaires relating to the perceived importance of CE knowledge areas and employability competencies, each group was also asked questions specific to the relevant stakeholder group. In the case of the academics, additional questions were asked about the current means of delivering such knowledge and competencies as well as the current means of assessing the effectiveness of delivery. The employers were asked to rate the perceived level of current graduates in each of the knowledge and competency areas as well as their current means of evaluating these during the process of recruitment. Finally, the graduate group were also asked to comment on the effectiveness of delivery of knowledge and competencies from their view point and suggest the most appropriate methods of delivery for each of the areas.

The questionnaires were implemented within Woofoo service and hosted on the iTeach central website (www.iteach-chemeng.eu/questionnaires). All consortium partners and associate partners were requested to send out the links to these questionnaires in May 2015 and the completion rates were monitored regularly. EC2E2N partners were also asked to complete the questionnaires and to disseminate the link to them as widely as possible. At the end of June 2015, all the responses were collected and analysed as described in section 4.

3.2 Focus groups

Following the initial data analysis from the questionnaire responses a template of questions was agreed by all partners for the focus group semi-structured interviews at each partner country (see Appendix 9.2). Where possible, representatives of each of the three stakeholder groups were invited to attend the focus group discussions (see Table 4.1 for details). The partner representatives facilitated the discussions around the agreed questions, keeping an audio recording of all discussions in the local language. A summary of the responses in English were sent to Partner 1 (UNEW) for analysis (see section 4.2 for details) and all responses and audio recordings were uploaded onto the secure area of the iTeach website.

4. Data analysis methodology

4.1 Quantitative statistical data analysis

Before any analysis was undertaken, the raw data was carefully screened. All personal information that would reveal a participant's identity was omitted from the data set. In the case of double-entries (i.e. a participant accessed the survey more than once), only the complete version was retained (after careful screening of IP address and personal information). Using the Statistical Package for the Social Sciences (SPSS), the quantitative data (i.e. all Likert-scale type questions) was analysed for descriptive information, including measures of central tendency (mean, standard deviation, minimum, maximum) and frequency counts. For single-choice questions, only frequency counts were conducted. In order to compare differences between geographical regions and, where applicable, between employment position and company size, independent-samples t-tests were conducted for all Likert-scale type questions as is recommended for normally distributed data (Field, 2005). 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. While the findings of these tests need to be interpreted with caution due to the relatively small sample sizes, they do provide some indication of trends in the data.

4.2 Qualitative data analysis

Open responses from the questionnaires screened as described in section 5.1 (to avoid duplicates) were analysed qualitatively. Thematic analysis (Braun and Clark, 2006) was employed on the open survey questions using the qualitative data analysis software package NVivo 10. Respondents' comments were initially sorted into broad analytical categories corresponding to the survey questions. In a second analytical step, every statement in the broad categories was analysed for content and placed under an appropriate heading or thematic 'node' along with any other responses which were sufficiently similar (Young and Schartner, 2014). This process generated a collection of sub-themes for each analytical category.

An additional qualitative analysis was carried out on the results of focus group interviews. These interviews were undertaken by the partner organisations in order to gain a more detailed understanding of the issues which arose from the questionnaire data. The interviews took place with graduates, academics and employers using a semi-structured interview schedule designed by P1 and agreed by all partners (see section 3.2 for details).

Table 4.1: Summary of focus groups carried out by all partners.

	Germany Aachen/	UK Newcastle	Bulgaria Sofia	Macedonia Skopje	Serbia Belgrade	France Lorraine	Portugal Porto	Slovakia

	Frankfurt							
Academics N = 52	√		√	√	√	√	√	√
Graduates N= 23		√		√		√	√	
Employers N = 34	√			√		√	√	√

The data from the focus groups took the form of transcripts of the actual words spoken during the interviews and/or summaries of the interviews. The analysis was undertaken by a Research Associate from the Research Centre for Learning and Teaching at Newcastle University and took place in two phases. During the first phase, the transcripts were analysed using the software package Nvivo 9. Each transcript was read through several times and the themes which emerged were assigned a code (see appendix 9.4 for the models of the phase 1 coding). These codes were then used in phase 2 to analyse the interview summaries. On the basis of this additional data, the original codes were modified and extended. The analysis has enabled a picture to be created which highlights both the similarities of experience and opinion across the partner countries, but also the unique and important differences.

4.3 Multivariate data analysis

Whilst the statistical analyses described in section 4.1 provided some indication of the trends in the responses of all three stakeholder groups to the questionnaire, Multivariate Data Analysis (MVDA) methods offer an additional opportunity to identify underlying multivariate correlations that could not be revealed through the simple statistical analyses (Glassey, 2013). Given the differences in the questionnaires for the three stakeholder groups, only questions relating to the perceived importance of CE knowledge and employability competencies (identical in each questionnaire) were used in this analysis. The Lickert scale responses to these questions from all three stakeholder groups were collected into a single file with 32 columns (one for each of the knowledge and competency areas). Given that some respondents did not rate every area of knowledge and competency, incomplete questionnaires (samples) containing N/A were eliminated during pre-screening. This resulted in 15.6% of the data being removed which changed the number of questionnaires completed by each group (academic, employer, graduate). Changes are summarized in Table 4.2.

Table 4.2: Summary of the matrix arrangement for MVDA analysis of questionnaire responses

Group	**Row numbers after Prescreen**
Academic	2-72
Employers	73-160
Graduates	161-227

Principal Component Analysis (PCA) was carried out by Partner 1 (UNEW) using an in-house developed software package within Matlab. The number of principal components retained for detailed analysis was selected on the basis of the cumulative variance explained. Scores plots and loadings plots were used to identify any trends in the responses as discussed in section 5.3.

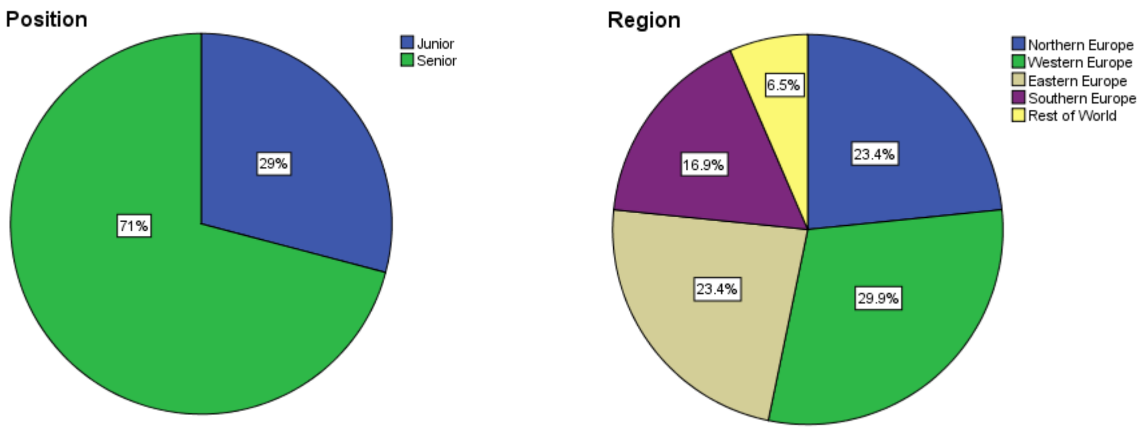
5. Results - questionnaires

5.1 Quantitative statistical data analysis

Detailed graphical analysis of responses to the Lickert scale questions is shown in Appendix 9.3 for each stakeholder group and only the main observations and group comparisons are presented here. Given the somewhat limited size of the samples in each stakeholder group, only limited conclusions could be drawn from these comparisons.

5.1.1 Academic questionnaires

Figure 5.1 demonstrates the demographic information of the academic respondents to the questionnaire both by their positi8on and the geographical area (see section 4.1). The graphical representation of all responses to all the quantitative questions is shown



A B

Figure 5.1: Demographic information on academic questionnaire respondents by position (a) and by geographical area (b).

As expected, senior academics represent the predominant proportion of respondents as they were targeted as a priority, given their experience in programme structures. The balance between various parts of Europe is reasonable (all around 23-24 %) and thus a comparison was carried out between these parts of Europe with the following results (Note: these comparisons should be treated with caution given the small sample sizes in each group).

Northern vs. Western Europe:

- Academics from Northern Europe rated 'Effective Use of Information Technology' significantly higher (N = 16, M = 4.50, SD = 0.52) than academics from Western Europe (N = 23, M = 4.04, SD = 0.71), t(37) = 2.21, p = 0.034.
- Academics from Northern Europe rated 'Information Literacy' significantly higher (N = 17, M = 4.47, SD = 0.72) than academics from Western Europe (N = 23, M = 3.91, SD = 0.79), t(38) = 2.29, p = 0.028.

Northern vs. Eastern Europe:

- Academics from Eastern Europe rated 'Chemistry' significantly higher (N = 18, M = 4.61, SD = 0.50) than academics from Northern Europe (N = 18, M = 4.06, SD = 0.73), t(34) = -2.67, p = 0.011.
- Academics from Eastern Europe rated 'Innovative Advanced Design' significantly higher (N = 15, M = 4.40, SD = 0.74) than academics from Northern Europe (N = 17, M = 3.71, SD = 0.92), t(30) = -2.34, p = 0.026.
- Academics from Eastern Europe rated 'Problem-solving skills' significantly higher (N = 15, M = 4.93, SD = 0.26) than academics from Northern Europe (N = 16, M = 4.63, SD = 0.50), t(29) = -2.14, p = 0.041.

Northern vs. Southern Europe:

- Academics from Southern Europe rated 'Chemistry' significantly higher (N = 13, M = 4.85, SD = 0.38) than academics from Northern Europe (N = 18, M = 4.06, SD = 0.73), t(29) = -3.59, p = 0.001.
- Academics from Southern Europe rated 'Process & Product Technology' significantly higher (N = 12, M = 4.75, SD = 0.45) than academics from Northern Europe (N = 18, M = 4.17, SD = 0.79), t(28) = -2.32, p = 0.028.

Western vs. Eastern Europe:

- Academics from Eastern Europe rated 'Chemistry' significantly higher (N = 18, M = 4.61, SD = 0.50) than academics from Western Europe (N = 23, M = 4.22, SD = 0.67), t(39) = -2.07, p = 0.045.
- Academics from Eastern Europe rated 'Awareness of Business Drivers' significantly higher (N = 15, M = 3.93, SD = 0.84) than academics from Western Europe (N = 23, M = 3.39, SD = 0.70), t(39) = -2.07, p = 0.046.
- Academics from Eastern Europe rated 'Effective Use of Information Technology' significantly higher (N = 15, M = 4.53, SD = 0.52) than academics from Western Europe (N = 23, M = 4.04, SD = 0.71), t(36) = -2.31, p = 0.027.

Western vs. Southern Europe:

- Academics from Southern Europe rated 'Chemistry' significantly higher (N = 13, M = 4.85, SD = 0.38) than academics from Western Europe (N = 23, M = 4.85, SD = 0.38), t(34) = -3.60, p = 0.001.

- Academics from Southern Europe rated ‘Biology’ significantly higher (N = 13, M = 3.69, SD = 0.48) than academics from Western Europe (N = 22, M = 2.91, SD = 0.81), t(33) = -3.16, p = 0.003.
- Academics from Southern Europe rated ‘Process & Product Technology’ significantly higher (N = 12, M = 4.75, SD = 0.45) than academics from Western Europe (N = 23, M = 4.30, SD = 0.56), t(33) = -2.38, p = 0.023.
- Academics from Southern Europe rated ‘Data Interpretation and Analysis’ significantly higher (N = 12, M = 5.00, SD = 0.00) than academics from Western Europe (N = 23, M = 4.70, SD = 0.47), t(22) = -3.10, p = 0.005.
- Academics from Southern Europe rated ‘Industrial Standards and Quality Assurance significantly higher (N = 12, M = 4.17, SD = 0.58) than academics from Western Europe (N = 23, M = 3.52, SD = 0.95), t(32) = -2.50, p = 0.018.

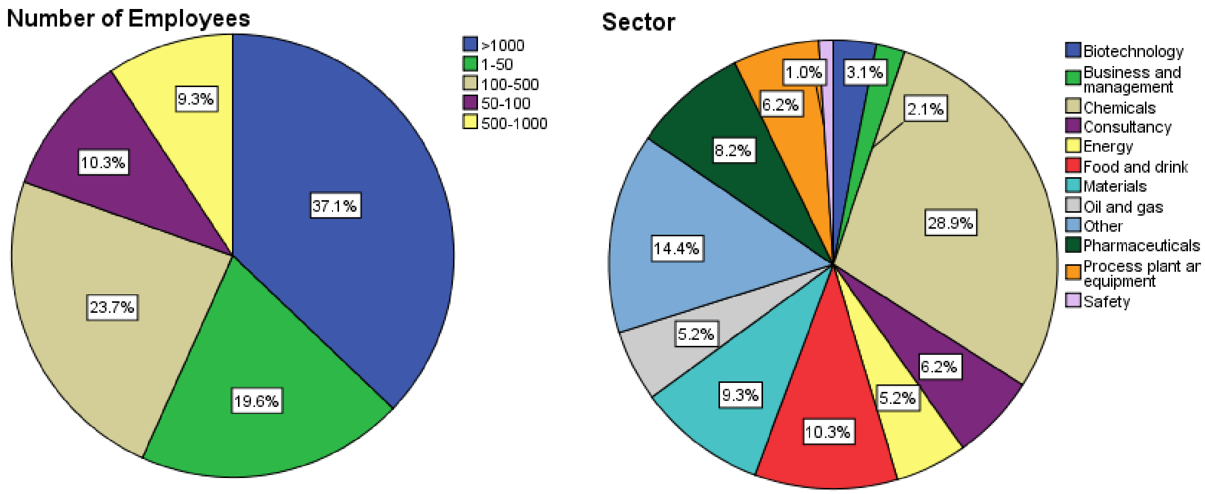
Eastern vs. Southern Europe:

- Overall, few group differences were found between academics from different regions.
- No statistically significant differences were found between academics from Eastern and Southern Europe, indicating similarity between these two regions in terms of importance attached to graduate attributes.

In terms of questions regarding the current predominant methods of delivery (see Appendix 9.3 for detailed graphs) the traditional lecture format represented the dominant form of deliver for all underpinning sciences, except for IT, and the majority of the core CE knowledge areas (with a particularly dominant delivery of fundamentals through lectures – 78%). Only in modelling, systems and process & product technology were lectures not representing the predominant method of delivery. For advanced CE depth and breadth at the master level education, lectures again represented the predominant method of delivery, although for the other aspects of advanced CE there is a significant contribution of problem based, case based and practical methods of delivery. The same is observed for the delivery of employability competencies.

5.1.2 Employer questionnaires

The responses from the employer group were dominated by responses from Southern Europe (60.8% of all responses) and thus geographical comparison was not carried out for this stakeholder group. However, it was interesting to note whether the3re were any differences between the employer perceptions based either on the size of the company or the sector in which it operates. Figure 5.2 shows the demographic distribution of the employer responses based on the size of the company (Figure 5.2 a) or the sector (Figure 5.2 b).



a b

Figure 5.2: Demographic information on employer questionnaire respondents by company size (a) and by the sector (b).

Although there was a slight over-representation of 'chemicals' sector, this was expected, given the industrial sector in which CE graduates find employability and hence no bias was considered in the responses of the employers. In order to balance the proportion of different size of companies, a comparison between the following groups were carried out: Small company (number of employees NE = 1-100, sample number N = 29), medium-sized company (NE = 100-1000, N = 32), large company (NE >1,000, N = 36).

In terms of differences observed between responses from various sized employer companies, there were very few significant differences summarised below (Note: these results should be treated with caution given the small size of the samples used in the comparisons):

Underpinning

- Small companies rated 'Physics' as more important (M = 4.29, SD = 0.60) than medium-sized companies (M = 3.78, SD = 0.75), t(58) = 2.85, p = 0.006.
- Medium-sized companies rather graduates as more competent in 'Chemistry' (M = 4.19, SD = 0.59) than small companies (M = 3.79, SD = 0.83), t(58) = -2.17, p = 0.034.
- Large companies rated 'Physics' as more important (M = 4.39, SD = 0.87) than medium-sized companies (M = 3.78, SD = 0.75), t(66) = -3.06, p = 0.003.

Core

- Medium-sized companies rated 'Safety' as more important (M =4.94, SD = 0.36) than small companies (M = 4.54, SD = 0.92), t(34.33) = -2.15, p = 0.039.
- Medium-sized companies rated graduates as more competent in 'Sustainability, Economics, Ethics' (M = 3.30, SD = 0.99) than small companies (M = 2.75, SD = 1.04), t(56) = -2.07, p = 0.044.
- Large companies rated 'Fundamentals' as more important (M = 4.69, SD = 0.58) than medium-sized companies (M = 4.30, SD = 0.65), t(63) = -2.52, p = 0.014.

Practice & Design

- Medium-sized companies rated graduates as more competent on ‘Practical Skills’ ($M = 3.76$, $SD = 0.79$) than small companies ($M = 3.21$, $SD = 0.92$), $t(55) = -2.41$, $p = 0.019$.

Employability

- Large companies rated ‘Communication Skills’ as more important ($M = 4.85$, $SD = 0.36$) than medium-sized companies ($M = 4.62$, $SD = 0.50$), $t(44.46) = -2.08$, $p = 0.042$.
- Medium-sized companies rated ‘Continuous Professional Development’ as more important ($M = 4.52$, $SD = 0.59$) than large companies ($M = 4.25$, $SD = 0.71$), $t(56) = 2.10$, $p = 0.040$.

5.1.3 Graduate questionnaires

For the graduate survey a number of potential biases were checked by exploring the proportions of respondents from companies of various sectors (see Figure 5.3 a), company size (Figure 5.3 b), geographical area (Figure 5.3 c) and the type of the job the respondent carried out (technical vs non-technical, Figure 5.3 d).

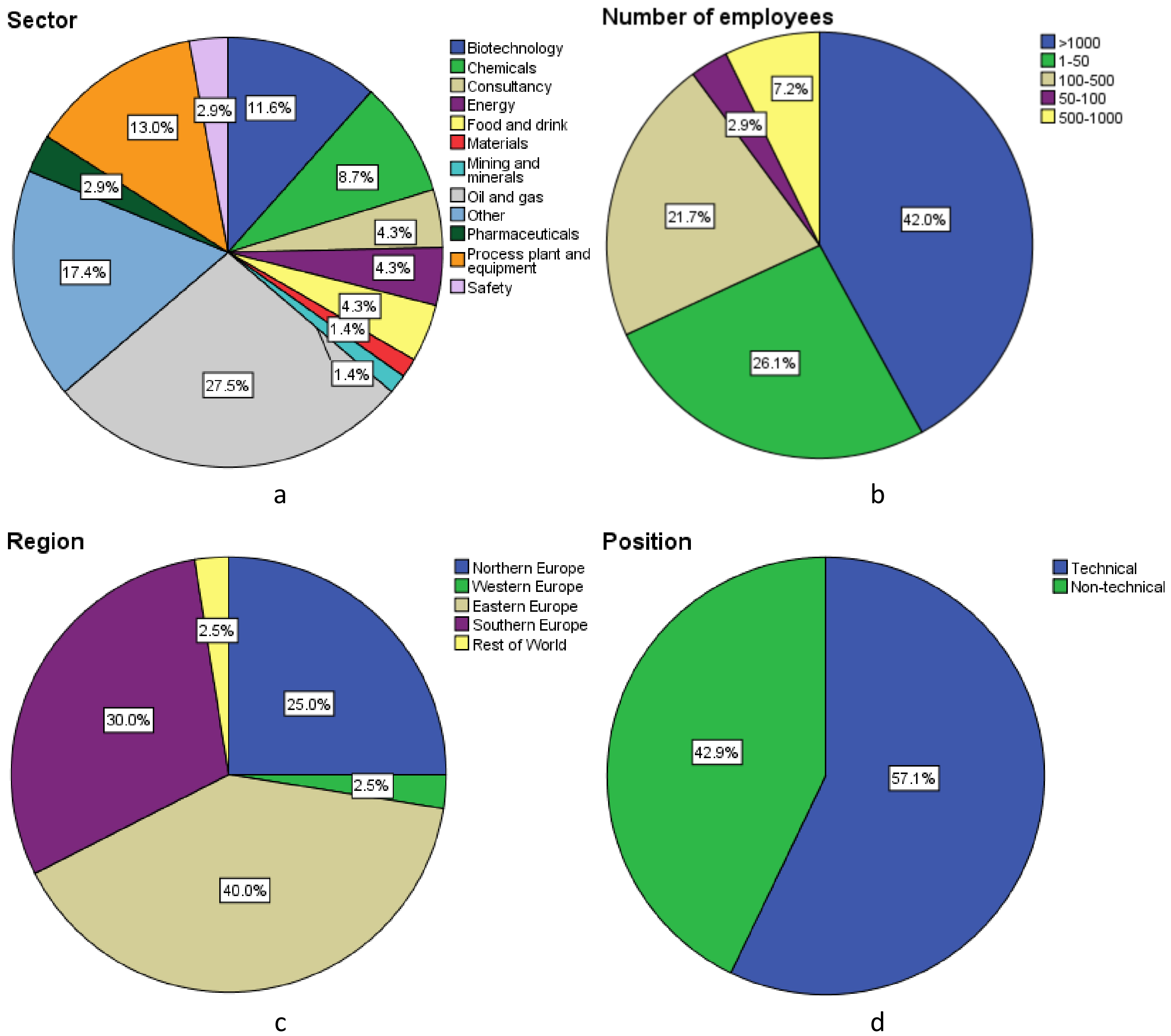


Figure 5.3: Demographic information on graduate questionnaire respondents by the sector (a), company size (b), geographical area (c) and by the position of the graduate in company (d).

Given the very low number of respondents from Western Europe, geographical group comparisons were only carried out between Northern, Eastern and Southern Europe. No significant difference were observed for group comparisons based on the size of the company or the position of the respondent. The latter is particularly re-assuring as even graduates in non-technical positions consider the core CE knowledge and employability competencies similarly important as those in technical positions. The only notable differences observed between the geographical groupings of graduates are shown below (Note: due to the low response rates, these conclusions should be treated with caution):

Underpinning

- Graduates from Southern Europe rated 'Case Studies' as more effective ($M = 4.42$, $SD = 0.67$) than graduates from Northern Europe ($M = 3.44$, $SD = 0.73$), $t(19) = -3.18$, $p = 0.005$.
- Graduates from Northern Europe rated 'Maths' as more important ($M = 5.00$, $SD = 0.00$) than graduates from Eastern Europe ($M = 4.13$, $SD = 0.62$), $t(15) = 5.65$, $p < 0.001$.
- Graduates from Northern Europe rated 'Lectures' as more effective ($M = 3.80$, $SD = 0.79$) than graduates from Eastern Europe ($M = 3.19$, $SD = 0.40$), $t(24) = 2.63$, $p = 0.015$.
- Graduates from Eastern Europe rated 'Case Studies' as more effective ($M = 4.50$, $SD = 0.52$) than graduated from Northern Europe ($M = 3.44$, $SD = 0.73$), $t(21) = -4.07$, $p = 0.001$.
- Graduates from Southern Europe rated 'Maths' as more important ($M = 4.75$, $SD = 0.45$) than graduates from Eastern Europe ($M = 4.13$, $SD = 0.62$), $t(26) = -295$, $p = 0.007$.

Core

- Graduates from Northern Europe rated 'Systems' as more important ($M = 4.40$, $SD = 0.67$) than graduates from Eastern Europe ($M = 3.53$, $SD = 0.74$), $t(23) = 2.62$, $p = 0.015$.
- Graduates from Northern Europe rated 'Sustainability, Economics, Ethics' as more important ($M = 4.30$, $SD = 0.48$) than graduates from Eastern Europe ($M = 3.47$, $SD = 0.92$), $t(22.13) = 2.96$, $p = 0.015$.
- Graduates from Eastern Europe rated 'Problem-based' as more effective ($M = 4.71$, $SD = 0.47$) than graduated from Northern Europe ($M = 4.11$, $SD = 0.78$), $t(21) = -2.33$, $p = 0.030$.

Practice & Design

- Graduates from Northern Europe rated 'Industrial Standards and Quality Assurance' as more important ($M = 4.50$, $SD = 0.53$) than graduates from Eastern Europe ($M = 3.54$, $SD = 0.97$), $t(21) = 2.83$, $p = 0.010$.
- Graduates from Northern Europe rated 'Technical Rigour in Design' as more important ($M = 4.50$, $SD = 0.53$) than graduates from Eastern Europe ($M = 3.67$, $SD = 1.07$), $t(20) = 2.24$, $p = 0.037$.
- Graduates from Northern Europe rated 'Awareness of Health, Safety and Environment Issues as more important ($M = 4.30$, $SD = 0.68$) than graduates from Eastern Europe ($M = 3.38$, $SD = 0.96$), $t(21) = 2.56$, $p = 0.018$.

5.2 Qualitative data analysis

Section 4.2 describes the method of analysing the free text responses to all three stakeholder questionnaires. The summary of these findings is given below for each stakeholder group depending on the specific questions addressed to the relevant stakeholder group.

Academics

In terms of the current methods of assessing the effectiveness of delivery in academia, the two major methods identified by the respondents were the performance of students in examinations and the use of satisfaction surveys. Among other individual responses mentioned by academics were peer observations, accreditation visits and national employment statistics of graduates. In terms of the effectiveness of delivering employability competencies, the predominant current methods of assessment still included student performance in assessment tasks (although project and lab reports were mentioned more frequently), student satisfaction surveys, oral presentations, feedback from external contributors to design projects and accreditation visits were identified amongst others, although comments indicated that a number of respondents did not believe there were specific methods of measuring the effectiveness of employability competency delivery.

Employers

In terms of current means by which companies assess the competencies of graduates, there was no single (or significantly predominant) methods of assessment, although CVs and references, performance in assessment centres and interviews, assessment against company specific proforma tasks and probation periods with evaluation of performance 'on the job' were mentioned by one or more respondents.

Graduates

Whilst a number of graduates indicated that lectures are an effective means of delivering underpinning and core CE knowledge, problem based and cased based delivery with practical industrial links were indicated as most effective means of delivery methods in all areas suggested by the predominant proportion of graduates regardless of any basis of grouping.

5.3 Multivariate data analysis

Principal Component Analysis was carried out as described in section 4.3 on a combined matrix of Lickert scale responses from all of the stakeholder groups (matrix size 227 x 32). Table 5.1 summarises the variance captured by each principal component (PC).

Table 5.1: Variance (% Var) and cumulative variance (% Cum. Var) captured by each principal component

PC	%Var	%Cum. Var
1	17.949	17.949
2	12.149	30.098
3	7.765	37.862
4	6.121	43.983
5	4.759	48.742

6	4.395	53.137
7	4.042	57.179
8	3.640	60.819
9	3.344	64.163
10	3.096	67.259
11	2.919	70.178
12	2.589	72.767
13	2.345	75.112
14	2.296	77.408
15	2.229	79.637
16	2.132	81.769
17	1.915	83.684
18	1.817	85.501
19	1.710	87.211
20	1.586	88.798
21	1.375	90.173
22	1.252	91.425
23	1.217	92.642
24	1.106	93.747
25	1.058	94.806
26	1.015	95.821
27	0.942	96.762
28	0.752	97.514
29	0.731	98.245
30	0.679	98.924
31	0.638	99.562
32	0.438	100.000

Clearly a large number of PCs (21) is required to capture just 90% of cumulative variance, indicating a high level of variability in the data. Score plots of all 21 PCs were plotted in order to identify any trends in the data, but since PC1, PC2, PC3 and PC4 individually capture the most significant amounts of variance, these are analysed in more detail here. Figure 5.4 shows the scores plots of the first four PCs against each other, representing each stakeholder group with a different colour to identify any potential multivariate differences between the groups.

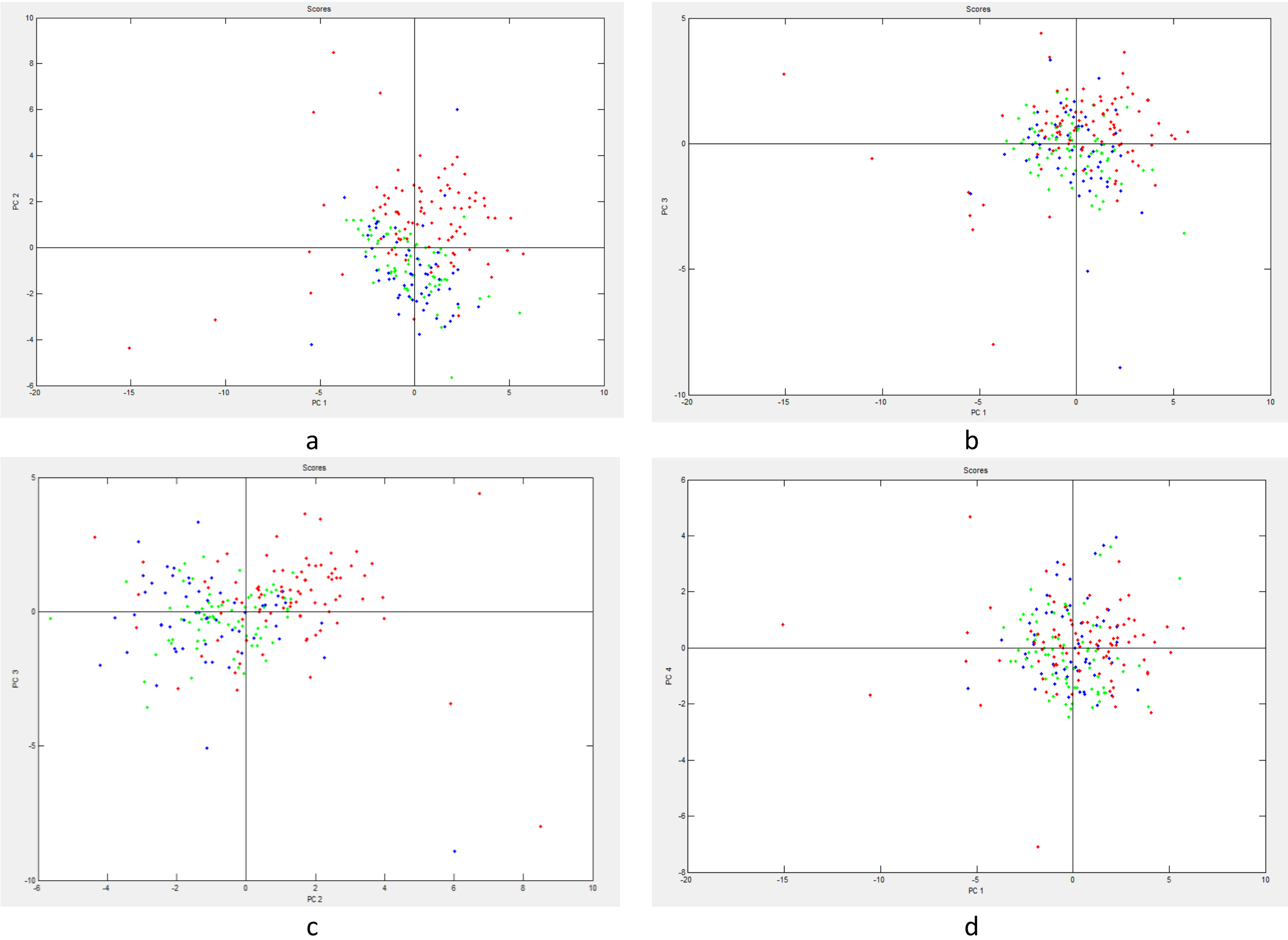
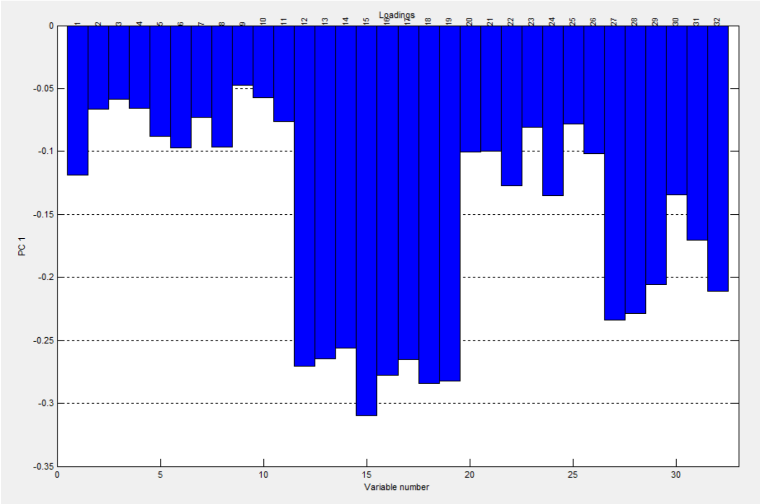


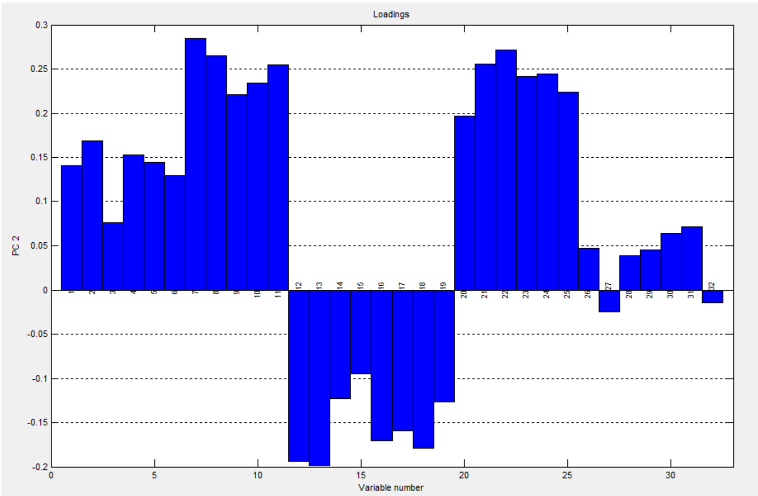
Figure 5.4: Scores plots of the first four principal components (capturing 44% of cumulative variance –see Table 5.1) of the PCA model built on all numerical responses from all stakeholder groups (academics = green, employers = red, graduates = blue). (a) PC1 vs PC2, (b) PC1 vs PC3, (c) PC2 vs PC3 and (d) PC1 vs PC4.

The scores plots are often useful in revealing multivariate features in the data that may indicate differences between groups of samples – in this case the three stakeholder groups, represented by three colours: academics in green, employers in red and graduates in blue. In this case however the analysis did not show a clear clustering or differences between the stakeholder groups, even when all combinations of PCs explaining up to 90% of cumulative variance were explored (data not shown). This was not unexpected, given the limited significant univariate differences detected and described in section 5.3. Clearly most of the responses in Figures 5.4 a-d are clustered relatively closely together with only a few outlying responses (predominantly from the employer and graduate groups) extending to the periphery of each of the graphs and indicating more extreme responses in each case. These could be explained possibly by a more specialist nature of the particular employer's / graduate's business, requiring more specific knowledge and competencies.

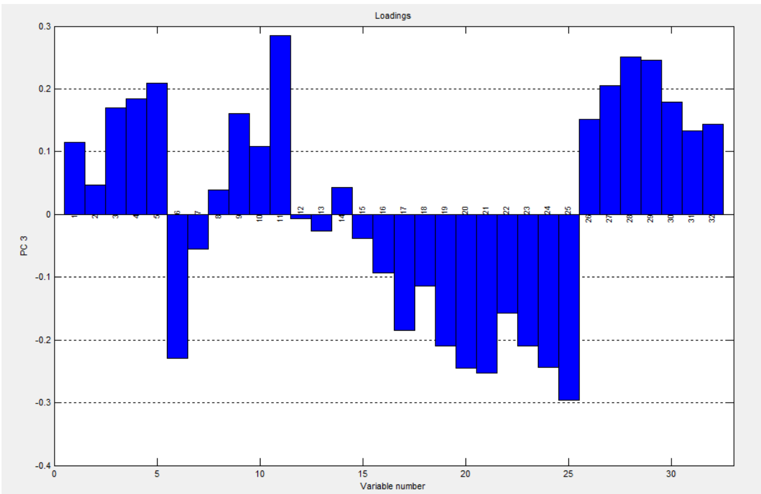
The only slight more generic trend that can be observed in Figures 5.4 a-c is a slight prevalence of red points (employers) in the top right quadrant (positive values of relevant PCs) compared to a no discernible differentiation of academic and graduate responses (blue and green points). In order to explore the possible reasons for this trend, the loadings plots of the first three PCs were examined to establish which responses influenced these PCs in particular (Figure 5.5 a-c).



a



b



c

Figure 5.5: Loadings plots of the first three principal components (capturing 38% of cumulative variance – see Table 5.1) of the PCA model built on all (32) numerical responses from all stakeholder groups. (a) PC1, (b) PC2 and (c) PC3.

Loadings of PC1 show that variables 12-19 have the dominant effect on this PCs. These variables relate to responses on engineering practice and design (practical skills, data interpretation and analysis, information literacy, industrial standards & quality assurance, systems approach and technical rigour in design and awareness of health and safety and business drivers). Similarly, PC2 loadings indicate an 'opposite' relationship between these responses and those relating to underpinning sciences and core chemical engineering (1-11) and advanced CE topics at master level (20-25). Finally PC3 loadings indicate that this PCs is more dominated by the employment competencies (26-32), including problem solving, team work, leadership, IT use, project and time management and continuous professional development. Another positive contribution to this PC is displayed by variables 11 (sustainability, economics and ethics) and 5 (IT). An opposite effect is indicated in this PC by variables 19-25, representing advanced CE topics at masters level, and variable 6 (CE fundamentals).

These observations are useful in the attempt to clarify the weak trend observed in the scores plots, indicating slight differences between the employer perceptions of importance of CE knowledge and employability competencies, compared to the academics and graduates. However, it is important to note that these differences are not sufficiently significant to result in clear separation of the clusters of responses and thus not sufficient in themselves to lead to firm conclusions.

6. Results – focus groups

Since all the focus groups were carried out in local languages, a summary of the discussions was produced by each partner in English, using an agreed template containing the questions highlighted below. This summary, together with the entire transcript of the focus group meetings held in English was analysed by the iTeach researcher, Dr Ulrike Thomas, employed by UNEW (partner 1), following the procedures described in section 4.2.

1) Do you agree with the questionnaire responses to the importance of CE knowledge areas (incl. underpinning and core CE)? Give reasons for agreement /disagreement

The consensus across all of the focus groups in each of the partner countries was that the core and underpinning knowledge areas identified in the questionnaires all need to be represented in CE courses. Creating a broad and balanced curriculum which provides students with a good basic understanding of the key concepts in CE is important because

- as a student you will not initially know which industry you are likely to work in:

I think biology's pretty important to me at the minute. It depends what industry you're gonna go in to, so at the minute I'm doing my research into biopharmaceuticals and biology's a big thing. It's hard to say which you think's most important cos it's subjective to what you're gonna do. It's a bit of a hard question to answer cos all of them are. *(graduate, UK)*

I agree, because I think the basic knowledge and the objects that make up the core of the CE are necessary to establish the profile of the engineer in the field of chemical engineering.

(Academic, Macedonia)

- the nature of the CE industry changes which means that some companies have to adapt their focus in order to sustain their businesses:

A shift was observed in a project plant design company in this context. They managed for decades with doing business for petrochemical and bulk chemicals company but nowadays, the majority of their customers belong to food, biotech and pharma industry. *(Employer, Slovakia)*

- R&D -which is vital to ensure that the CE industry remains innovative- requires excellent technical knowledge.

However, it was acknowledged by some interviewees that the local context can have an impact on the curriculum offered to students in particular institutions. For example, in some countries the CE departments are small because the CE industry is not well-developed and job opportunities are scarce:

Recently the industry in Macedonia is not so developed, so that the need for chemical engineers is not so big, so that the graduated engineer has difficulties finding appropriate job position

(Graduate, Macedonia)

Some countries are also dominated by a particular kind of industry, which again may require CE departments to focus on specific subjects:

The industry in Macedonia which is mostly developed is the food industry, and the foreign investments are focussed on food industry, and the importance of biology is big.

(Graduate, Skopje)

Many respondents cited the importance of connecting the core and underpinning knowledge to actual industrial examples so that the theories have meaning and are therefore more easily understood:

Use practical applied examples, be proactive in information *(Research Engineer, Exxon, France)*

It still feels like there is a gap between University and industry, so in terms of seeing how equipment works…..

……it's about having more exposure, it's all very theoretical *(graduate, UK)*

Master education fundamental courses should not be taught as fundamentals rather but in combination with applications / labs / projects) *(Academic, Germany)*

2) Do you agree with the questionnaire responses to the importance of employability competencies? Give reasons for agreement /disagreement

There was consensus across the interviews that it was important for students to be provided with teaching and learning experiences that allow them to develop their employability competences. The specific competences identified in the questionnaires i.e. problem-solving, communication, working effectively with others, leadership, project planning, time-management and effective IT use, were acknowledged as important, although there was a large variation amongst the participants as to which were considered most important for example:

Communication is the most important *(Academic, Germany)*

Yes I agree, having problem-solving skills is very important for employability competences
(Graduate, Macedonia)

An interesting feature to come out of the data is that many students and employers feel that there are important employability competences which are not being addressed by current CE courses. These relate strongly to the notion of business management i.e. entrepreneurship, Human Resource Management, cash flow, managing uncertainty:

Importance of business drivers, be able to work in groups, to be able to take some decisions in the context of uncertainty (student, France)

Project planning and time management should be strengthened. Business plan focus should be added to core competences (employer, Portugal)

In industry the focus is completely different….and I don't think we're adequately taught that in terms of a business focus (graduate, UK)

One focus group participant also identified the importance of learning the English language in order to improve their career progression:

Some graduates fail to get a good position because a good command of English is an absolute must in many of the largest companies which are multinational. (academic, Slovakia)

3) What methods of delivery do you believe are most effective for CE knowledge? Justify.

The traditional course delivery structure of lectures, tutorials and labs was generally supported across all of the partner countries, as a means by which to deliver both core and underpinning CE knowledge. The rationale given for this was that it is important to have a good understanding of CE theory before it can be applied to problems:

I think that the basic knowledge must be acquired during the lectures and exercises and it can be applied to solve specific problems of practice (academic, Macedonia)

Only in Slovakia was a different delivery structure identified; that of 'computational seminars' which was described by both academics and employers as a 'traditional and significant part of teaching'.

However, despite the support for the traditional structure of delivery, there was a very strong argument put forward by all of the interview participants that practical work, problem-solving, and real-life case studies were a vital part of teaching CE knowledge. The following quotations are typical of the many comments made during the interviews:

I think that for me personally case studies and problem-based learning is the best way to learn because obviously you have to get it right in your head in order to be able to work through the problems. (graduate, UK)

Importance of learning by doing, not just by watching and listening. (employer, France)

In my opinion, a stronger focus on practical applications strengthens long term understanding.
(Academic, Germany)

What is clear from the data, is that a balance of teaching methods needs to be adopted in any course so that both theory and practice are adequately introduced to students.

The participants in the interviews also highlighted a range of other factors that they feel play an important part in the effective delivery of CE content knowledge:

- Professors who have a 'good rapport' with their students (graduate, UK), who are of a 'high quality' (academic, Bulgaria) and who have had 'some experience of industry' (graduates, Macedonia)
- A good progression from lectures to tutorials to problem-solving/case studies, so that each builds on the other

I think so long as there's a good progression between all of them so if there's a good interactive lecture, where you're keeping focussed, moving on to a good tutorial with effective feedback and then you apply all that to a case study, I think that's probably the perfect progression
(graduate, UK)

- Teaching that is interactive and of an appropriate duration

'Be proactive' 'active pedagogy' 'more interactive formations' *(graduates, France)*

When you have a lot of lectures back to back… it's very hard to keep that focus
(graduate, UK)

- E learning

self-training and e learning methods are interesting when accompanied by a project
(graduate, France)

4) What methods of delivery do you believe are most effective for employability competencies? Justify.

There was agreement across all of the focus groups that employability competences could only be delivered through creating opportunities for students to experience real-life industrial problems/projects. This can be achieved either through actual placements/internships in a range of CE industries or through the simulation of problems within the university setting. An example of the latter is the 'design project' which forms part of the Undergraduate course at Newcastle University, UK:

in the design project …you'd learn all these fundamental skills and all this design stuff and then in the third year you get to actually design a chemical process and all the operations and the financial stuff and it's the first time you get to work as a and you get to put all this together *(graduate, UK)*

The aim of the simulations and industrial placements was clearly articulated as needing to create opportunities to develop: teamwork, project management skills, leadership skills, applied technical knowledge, and financial competence.

Suggestions for creating opportunities to develop employability competences included:

- Industrial placements/internships
- Problem-solving activities across all courses, not just add-ons
- Make students do presentations and grade these
- Role-play activities

5) What methods do you believe are most objective/ robust for assessing the effectiveness of CE knowledge delivery? Justify.

There was less agreement across the interviews regarding how CE knowledge should be assessed. It was clear however that the focus group participants felt there should be a range of methods included in any course that would enable all students to demonstrate their knowledge in a fair and robust manner:

Due to the diverse nature of knowledge within a CE curriculum, a combination of methods would be probably the better suited approach: example written tests and practical exams balanced with continuous assessment. *(employers, Portugal)*

The following are the main opinions/suggestions highlighted within the interviews:

Exams: these were acknowledged by many of the interview participants as a time-efficient, workable way to test the knowledge of individuals within large groups of students, but limited in terms of what they actually allow students to demonstrate. The reason cited for this is that students cram for exams but then quickly forget what they have learnt. The following were some typical responses:

Exams are fast to correct but not very effective *(Academic, Germany)*

I know from personal experience that I do an exam and forget about it and that when I come to do something that may require that at a later date I have to go back and re-teach myself because there's so much to learn and I've never actually applied or used it. *(graduate, UK)*

Suggestions to improve exams included having oral exams (Germany, Portugal) and longer open-book exams (UK), exam papers that contained problems (Macedonia)

Problem- based/case-study assessment: this from of assessment was identified across all of the partners and by all of the stakeholders as an effective means of testing CE knowledge:

Problem-based method and case studies are ones that are most appreciated methods to see or evaluate how the student attempts to solve them *(academic, Macedonia)*

Case studies/project reports are more appropriate *(academic, Germany)*

Assessment of work on problem-oriented case studies *(academic, Serbia)*

Student1: I think that a big case study every year would be a useful thing to do…

Student 2: and that links, incorporates many of the things you've done that year. I think that's much more useful than doing an exam *(graduates, UK)*

It was acknowledged that assessing case studies, design projects would be difficult but suggestions for aiding this included: peer-assessment, individual defence (VIVA style oral exam) and through professors examining sections they felt confident to assess.

S2: if you had a technical expert marking the technical design, somebody else marking the way it's written and somebody else marking the presentation I think that might be slightly better- a way of making it that we have the skills for when we go into industry *(graduate, UK)*

6) **What methods do you believe are most objective/ robust for assessing the effectiveness of employability competency delivery? Justify.**

The consensus across the partners is that the CE employability skills are actually quite hard to assess, but as was discussed in question 2, they are skills that need to be developed. A range of assessment methods were proposed:

- Interviews

Interviews are better for evaluation of effectiveness but more difficult to quantify a grade
(academic, Germany)

- Peer assessment

Peer assessment would have a place here, especially with respect to assessing communication competences *(graduates, UK)*

- Presentations

Oral presentations, group presentations, pitch presentations to potential employers and receiving immediate feedback *(academics, employers, graduates, France)*

- Feedback from work- placements

Internships, interview of industrial responsible for the internship *(employer, France)*

The best way to assess the effectiveness of employability competence is to have a future graduate in the company during a trainee assignment *(employer, Slovakia)*

- Projects and cases studies, with alternating roles for participants (possibly multi-disciplinary)

Real-life design challenges

- Role play

Role play where everyone takes on an assigned role *(graduates, France)*

7) Most frequently cited methods of effectiveness evaluation were exams and questionnaires (academia) or interview/training centre (employers). What are your views on the suitability of these methods within the proposed framework?

The analysis of the interview data has highlighted a diverse and strongly- argued range of opinions regarding how to appropriately assess CE knowledge and employability skills- as has been demonstrated in the responses to questions 5 and 6 above. The consensus would appear to be that all courses require a balanced portfolio of assessment methods that is both workable for the academics, but is relevant and useful for students.

Due to the diverse nature of knowledge within a CE curriculum, a combination of methods would be probably the better suited approach: example written tests and practical exams balanced with continuous assessment. *(employers, Portugal)*

7. Conclusions

This report set out the importance of establishing a robust and objective framework for measuring the effectiveness of delivery of core CE knowledge and employability competencies, which is the main aim of the iTeach project. A summary of the review of intended learning outcomes set by various national accreditation and governmental bodies is presented here, indicating a very consistent approach to the requirements for the formation of the future generations of chemical engineers across Europe and worldwide. A detailed methodology for collecting responses from all three stakeholder groups (academics, employers and graduates) on the importance of various areas of CE knowledge and employment competencies, current methods of delivering these as well as the current methods of assessing the effectiveness of their delivery is also described. Detailed univariate and multivariate statistical analysis of numerical responses as well as a structured approach to the analysis of free text responses is described.

The univariate statistical analysis of the numerical results of the questionnaires indicates a high degree of consistency in the responses between various geographical areas of Europe in terms of the significance of areas of knowledge and employment competencies with only a small number is differences observed in particular areas and summarised in the report. Also, a predominant method of delivering these was identified as traditional lectures for the vast majority of knowledge areas and alternative project/case based and practical approaches to the delivery of employability competencies. However, the low number of responses in each stakeholder group does not warrant these observations to be considered as highly reliable.

Multivariate data analysis of the numerical responses, using Principal Component Analysis method, indicated only a slight difference in the responses of the employers from those of the academics and graduates. These differences were predominantly due to the difference perception of the importance of the engineering practice and design knowledge, followed by the differences in the underpinning and core CE knowledge and advanced CE knowledge at masters level and finally by some differences in the employability competencies. However, these differences were not sufficiently significant to result in clear clustering of various stakeholder groups and thus cannot be considered as highly significant. Once again, this is partly due to the relatively low number of responses available for analysis.

The analysis of free text responses to the questionnaires indicated that the current means of assessing effectiveness of delivery in the academic environment centre around examination performance and student satisfaction questionnaires with more project based assessment and presentations for the employability competencies. From the employer perspective, the assessment methods include CV and references, performance during the interview and assessment centres as well as 'on-the-job' performance during probation periods.

The initial results of the questionnaire response analysis were subsequently used as a starting point for focus group discussions. Each partner organised focus groups including representatives of academics, employers and graduates (inviting predominantly those not responding to the questionnaires). These focus groups enabled us to explore further the themes emerging from the questionnaires in order to clarify the importance of various factors for the inclusion into the assessment framework. The analysis of the focus group transcripts re-enforced the initial findings of the questionnaires in terms of the importance of various areas of CE knowledge and employability competencies. It also indicated the concerns regarding the validity and the robustness of the current methods of assessing the effectiveness of delivery, although no specific suggestions for better means were introduced by the focus group participants. iTeach project WP3 will now take the outcomes of these analyses, together with detailed literature review and, using engineering decision making tools, it will propose a draft version of the assessment framework to be tested in pilot studies at partner institutions.

8. References

ABET Criteria for Accrediting Engineering Programs, 2012 – 2013, http://www.abet.org/DisplayTemplates/DocsHandbook.aspx?id=3143#sthash.r7bz7jH3.dpuf

ASIIN, Subject-specific criteria relating to the accreditation of Bachelor's and Master's degree programmes in mechanical engineering, process engineering and chemical engineering Germany, 2011

Braun, V., & Clark, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology,* 3(2): 77-101.

Cabrera, AF, Colbeck, CL, Terenzini,PT (2001): Developing performance Indicators for Assessing Classroom Teaching Practice and Student learning: The case of Engineering, *Res. in HE* 42.

Chalmers, D (2007): A Review of Australian and International Quality Systems and Indicators of Learning and Teaching. Chippendale NSW, The Carrick Institute for Learning and Teaching in Higher Education.

Commission for accreditation and quality assurance, Serbia; http://www.kapk.org

EC2E2N (2015): Chronology of the Network, http://www.ec2e2n.net, accessed 16.02.2015.

EFCE Bologna recommendation, http://www.efce.info/Bologna_Recommendation

Engineers Australia, Accreditation management system education programs at the level of professional engineer, https://www.engineersaustralia.org.au/about-us/accreditation-management-system-professional-engineers

Field, A. 2005. *Discovering Statistics Using SPSS.* 2nd ed. London: Sage.

Forum for Future "The Engineer of the 21st Century Inquiry - Engineers for Sustainability," 07 2000. [Online]. Available: www.forumforthefuture.org, accessed on 15.12.2012

Glassey J (2013): Multivariate Data Analysis for Advancing the Interpretation of Bioprocess Measurement and Monitoring Data, *Adv. Biochem. Eng. Biotechnol*, **132**, 167-191

IChemE accreditation guidelines revision (EAF, Mar 2014)

Molzahn, M (2004): Chemical Engineering Education in Europe: Trends and Challenges, *Trans IChemE, Part A, December, Chemical Engineering Research and Design*, 82(A12): 1525–1532

MÜDEK, Association for Evaluation and Accreditation of Engineering Programs, Criteria for Evaluating First Cycle (bachelor) Engineering Programs, Available on http://www.mudek.org.tr accessed on 15.12.2013

National Academy of Engineering (2009): Developing Metrics for Accessing Engineering Instructions: What gets measured is what gets improved. Washington DC: National Academies Press.

National Evaluation and Accreditation Agency, available on http://www.neaa.government.bg/en access date 04.02.201

Publication Analysis and overview of NQF developments in European countries. Annual report 2012, available on http://www.ond.vlaanderen.be/hogeronderwijs/bologna/qf/national.asp , accessed on 03.02.2014

Ružica Beljo Lučić et all. CROQF_Introduction_to_qualifications, available on http://www.azvo.hr/index.php/en/visoko-obrazovanje/dokumenti accessed on 03.02.2014

Slovak accreditation requirements for chemical engineering degrees,

Tryggvason, G, Apelian, D (2012): Shaping our world: Engineering education for the 21st century. Wiley & Sons, Hoboken, New Jersey

Young, T.J., & Schartner, A. (2014). The effects of cross-cultural communication education on international students' adjustment and adaptation. *Journal of Multilingual and Multicultural Development*, 35(6): 547-562.