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Making programme learning outcomes explicit for students of process and chemical engineering

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ABSTRACT

There is a global shift in education from solely content-driven teaching to teaching that takes learning outcomes into account. This movement underpins much of the educational reform in the area of engineering education. Programme learning outcomes for degrees in engineering education are more commonplace as more and more professional accrediting bodies require fulfillment or compliance with prescribed learning outcomes. However, the students may not be presented with these learning outcomes as they are often “hidden” in documentation submitted by institutions for accreditation purposes and hence may not be divulged to students. Undergraduate students (2006–2008) taking the BE degree programme in Process & Chemical Engineering at UCC were first surveyed to assess their level of knowledge of the learning outcomes concept and of the degree programme learning outcomes. The contents of two documents used in applications for accreditation by professional accreditation bodies as well as professional Institution guidelines were reviewed to formulate the degree programme learning outcomes which were presented to the students. These students were then surveyed after the presentation. The results of the questionnaire completed by students demonstrated a major improvement in their knowledge of both the concept of learning outcomes and also of the degree programme learning outcomes. It also showed that the students found the session to be of overall beneficial value.

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1. Introduction

Learning outcomes are statements of what a student is expected to know, understand and/or be able to demonstrate after completion of a process of learning (ECTS Users' Guide, p. 47, 2005). The traditional way of designing modules and programmes was to start from the content of the course. Teachers decided on the content, planned how to teach this content and then assessed the content. This type of approach focussed on the teacher's input and on the assessment in terms of how well the students absorbed the material. This approach to teaching is commonly referred to as a teacher-centred approach. It has also been characterised widely as the “empty vessels model” and is an approach which has been widely used throughout many scientific and technical disciplines; “Most science courses are taught with the belief that students are “empty vessels” that need to be filled with large amounts of informa-

tion” (Barman and Allard, 1993). A criticism of this approach is that it can be difficult to state precisely what the student is capable of doing after passing a module or programme.

International trends in education show a shift from the “teacher-centred” approach to a “student-centred” approach (Kennedy, 2007). This alternative model focuses on what the students are expected to be able to do at the end of a module or programme. Hence, this approach is referred to as an outcomes-based approach where learning outcomes are used to express what students should be capable of doing at the end of the process of learning. With the implementation of the Bologna Process by 2010, all modules and programmes throughout the participating countries must be expressed using learning outcomes.

There is a global shift from solely content-driven to outcomes-driven engineering education which underpins much of the educational reform currently being undertaken

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by universities, government and professional organisations around the world. This began in the USA in the 1990s, where industry, government and academia gathered together to consider the future of engineering education. Academia focussed on curriculum reform but industry considered the attributes of graduates that they desired. For industry, it is important to have a broader set of attributes, in addition to technical knowledge and ability, on which the engineering schools traditionally focussed. These attributes included areas such as communication skills, group skills, awareness of societal and global issues, ethics, professionalism and life-long learning skills. Focussing on these graduate attributes shifted the attention towards what students are capable of doing (i.e. learning outcomes) as opposed to focussing purely on curriculum content. This represented a major change in the philosophy of education for engineers. The interaction between industry and academia led to the establishment of ABET Inc. (originally known as the Accreditation Board for Engineering & Technology). The function of ABET was to set criteria for various engineering programmes and verify proper alignment with the criteria by the engineering colleges and schools in the USA (Cobb et al., 2007). In 1997, ABET introduced EC (*Engineering Criteria*) 2000, which listed the criteria for accrediting engineering programmes (ABET, 1997). There were 8 criteria used in assessing accreditation. Criterion 3 was entitled "Program Outcomes and Assessment" which consisted of a set of learning outcomes. To satisfy criterion 3, a programme must show that these learning outcomes are being assessed and achieved by the system previously used for accreditation. In the past, the approval of new study programmes was based mainly on input criteria, i.e. curriculum content and curricula-based examination guidelines. ABET initiated an outcomes-based approach to Engineering education at undergraduate level, which focused on what the students could do and what employers could expect from them. The ABET engineering criteria changes the way that programs are evaluated and thus changes the way courses are designed, as well as how they are taught and assessed.

The approach adopted by ABET signalled a similar shift in other countries and introduced accreditation based on outcomes rather than inputs, thereby enabling flexibility and the intention to drive innovation in engineering education. In the UK, organisations such as the Institution of Chemical Engineers (IChemE) also introduced accreditation processes based on learning outcomes including awareness of the broader contexts of engineering practice (IChemE, 2001). The version of IChemE's accreditation guidelines in the UK describes a minimum and distinctive core in terms of learning outcomes that a graduate from an accredited course should have acquired. In Ireland, the Institution of Engineers of Ireland introduced a learning outcomes based accreditation process in 2003 (Institution of Engineers of Ireland, 2003). This Institution stated just six learning outcomes which are somewhat similar to those presented by ABET. The Bologna process is the major driver of the implementation of learning outcomes throughout higher education in Europe (Molzahn, 2004) and is leading to the implementation of the learning outcomes approach throughout higher education in all of the 46 countries that have signed the Bologna Agreement.

In Australia, a national review of Australian Engineering Education (IEAust, 1996) called for change in the culture of engineering education (Crosthwaite et al., 2006). It reported that there was too great an emphasis on technical skills and

not enough cognisance of the broader role of engineering practice. In line with the review recommendations, accreditation of engineering professionals in Australia is now based on demonstrated development of graduates with attributes reflecting these values, i.e. an emphasis on achieving the specified learning outcomes.

The learning outcomes concept is spreading throughout higher education on a global scale. It is now commonplace to see programme or module descriptions containing learning outcomes which students can consider before they enroll on a course or module. In engineering education, degree programme learning outcomes are becoming more commonplace as more and more professional accreditation bodies require achievement of prescribed learning outcomes. However, these learning outcomes may not actually be made explicit to the students as the learning outcomes are often "hidden" in application for accreditation documentation rather than being presented to the students. This is the context of this paper which focussed on undergraduate students in the Department of Process & Chemical Engineering in UCC. The objectives of the study were:

1. To assess the initial level of knowledge of learning outcomes amongst the students.
2. To "unlock" the contents of two applications for accreditation documents and formulate the degree programme learning outcomes in a format that is presentable to students.
3. To present the learning outcomes approach and the degree programme learning outcomes to the students.
4. To assess the impact on the students of the presentation of the learning outcomes.

2. Methodology

The methods used are described below in the context of each of the project objectives outlined in the introduction.

- *Objective 1:* a questionnaire was used to assess the students' initial knowledge of learning outcomes. The use of a questionnaire is a suitable method for achieving objective 1 because the objective is straightforward, i.e. to gather relevant data. The questionnaire was carefully constructed and reviewed by two colleagues. The questionnaire approach was an easy method to quickly survey all the students in the undergraduate programme.
- *Objective 2:* achieving this objective involved primarily documentary research and to a lesser extent by carrying out semi-structured interviews with some lecturing staff. Most of the required data were obtained from accreditation guideline documents published by the Institution of Chemical Engineers (UK) and the Institution of Engineers Ireland, and from accreditation application documents submitted by the Department of Process & Chemical Engineering to both these institutions over the last 4 years. Once the relevant information was gathered, a document was drafted showing the Learning outcomes of the degree programme in University College Cork and the structure showing which modules are striving to attain the programme learning outcomes. It also provided the students with an explanation of the learning outcomes approach, what it is, why it is worthy of consideration and why it is useful to students. The draft document was reviewed by Department lecturing staff

2. How would you rate your level of confidence in being able to explain the concept of a learning outcome to another person?

Very confident Fairly confident Not sure Poor confidence Very poor confidence

Please comment _____

—

3. How would you rate your level of confidence in being able to write down the Learning Outcomes of your degree programme?

Very confident Fairly confident Not sure Poor confidence Very poor confidence

Please comment _____

4. Has anyone in the Department explained to you what are the learning outcomes of the degree programme in Process & Chemical Engineering?

Yes No

If Yes, please explain briefly _____

Fig. 1 – Questions 2, 3 and 4 of the Knowledge of Learning Outcomes Questionnaire.

in order to obtain their input into the drafting of the final document.

- *Objective 3*: a PowerPoint presentation, based on the learning outcomes document, was created and presented to first and fourth year students. In addition, the document discussed above was circulated to these students at the presentation.
- *Objective 4*: the method used to achieve this objective was to survey the students using a questionnaire. The reasons for this approach are similar to those outlined under objective 1 above, i.e. to gather relevant data. The questionnaire used was somewhat similar to the first questionnaire used to answer the research question outlined in objective 1 above. The second questionnaire contained specific questions designed to assess if the presentation session was of value to the students and to gain some additional feedback from them. Direct comparison with the results obtained from the student questionnaire at the beginning of the project was used to assess if there is an improvement in student knowledge of the learning outcome concept and the degree programme learning outcomes.

The qualitative data were analysed using the recommended procedures in literature (Cohen et al., 2000; Wellington, 2000) to ensure that the sample responses quoted in this paper are representative of the themes that emerged from the analysis of data.

3. Assessing the initial level of knowledge of learning outcomes amongst students

In this section a report is given of the analysis of data gathered from the questionnaire used to assess the initial level of knowledge of learning outcomes amongst the undergraduate students in the Department of Process & Chemical Engineering. The questionnaire was designed to assess that the students had a correct understanding of the concept of learning outcomes rather than mere knowledge of the correct definition of a learning outcome. Hence, levels of confidence

(using a Likert scale) reexplaining the concept of a learning outcome were used in the questionnaire rather than simply asking for knowledge of the definition of a learning outcome. Questions 2, 3 and 4 of the questionnaire are presented in Fig. 1 and this is followed by a summary and analysis of the student responses to these questions.

Q2 How would you rate your level of confidence in being able to explain the concept of a learning outcome to another person?

A summary of student responses to this question is presented in Fig. 2.

Analysis of the above data shows that:

- Less than 5% of students stated that they were “very confident”.
- Almost 50% stated that they were “fairly confident” and almost 50% stated that they were either unsure or not confident.

From reviewing the comments made by students, it is clear that those who stated they were “fairly confident” do not really have a good understanding of the concept of a learning. For these students, learning outcomes are things that you know or understand from completing a course. For example, some of these student’s comments include: “Learning

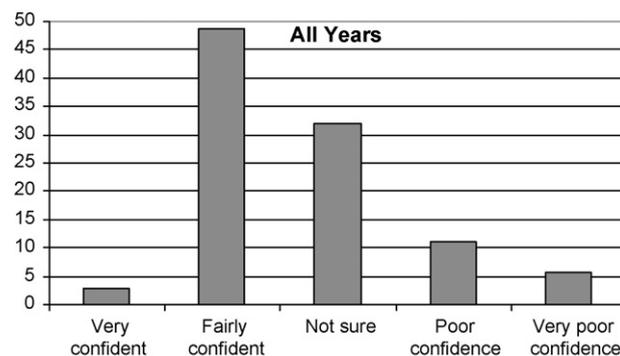


Fig. 2 – Summary of student responses to question 2.

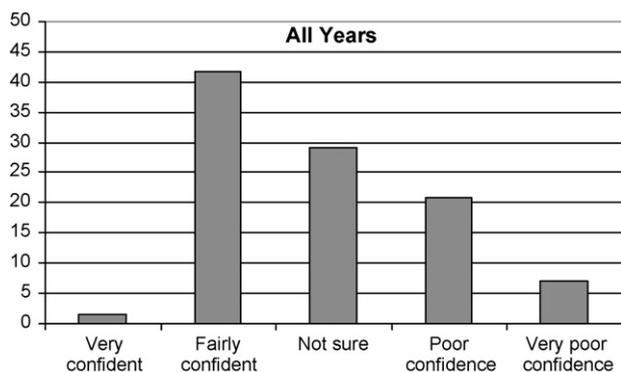


Fig. 3 – Summary of student responses to question 3.

outcomes—what you're supposed to know/taught at end of year"; "A learning outcome is simply what you are supposed to know at the end of the day". Overall, it can be concluded from the data that there is a need to educate students about the learning outcomes concept.

Q3. How would you rate your level of confidence in being able to write down the Learning Outcomes of your degree programme?

A summary of student responses to this question is presented in Fig. 3.

Analysis of the data clearly shows that:

- Less than 2% of students stated that they were "very confident".
- Around 42% stated that they were "fairly confident". However, over 50% stated that they were either unsure or not confident.

From reviewing the comments made by students, those who stated they were "fairly confident" appear to be using their own perception to attempt to state what they would know or understand from completing a course. As stated by one of these students (second year), the students "have a rough idea of the course and the different topics to be covered". A fourth year student stated that a student "might be able to write about some of the outcomes, might not realise some of them". Another second year student stated that the first year module "PE1003 was very helpful in defining the learning outcomes of this degree". This module, entitled "Introduction to Process and Chemical Engineering", did not explicitly state programme learning outcomes but gave an overview of chemical engineering, and in so doing, it implicitly provided an overview of the degree programme as a whole. Overall, it can be concluded from the data that over half the students are unsure or have poor confidence in their ability to write down the programme learning outcomes of their degree programme. Some of the students have a perception of the programme learning outcomes but only in a general sense. Thus, there is a clear need to spell out in detail the programme learning outcomes to the students.

4. Has anyone in the Department explained to you what are the learning outcomes of the degree programme in Process & Chemical Engineering?

A summary of student responses to this question is presented in Fig. 4.

These data clearly show that:

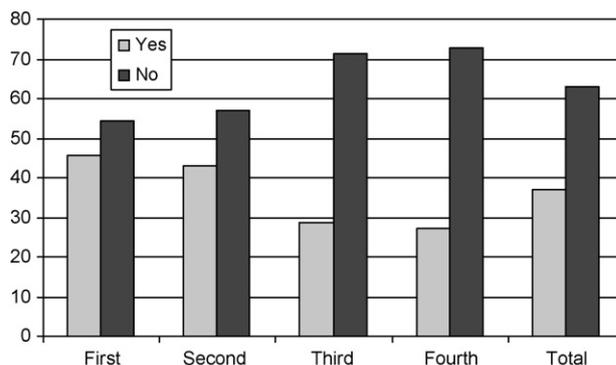


Fig. 4 – Summary of student responses to question 4.

- Over 60% of the students stated that the learning outcomes for the degree programme were not explained to them.
- The percentage number of "No"s is greater amongst the third and fourth years than the first and second years. However, all years had a greater percentage of "No"s.

A detailed analysis of the students' comments showed that many of the students who stated "Yes" obtained their knowledge from one particular module (PE1003 Introduction to Process and Chemical Engineering) taught by a member of staff to first year students. While the programme learning outcomes do exist in the Department accreditation documents submitted to Institution of Chemical Engineers (UK) and the Institution of Engineers Ireland, it appears that these are not communicated to the students.

From this survey, it is clear that there is a need to present and explain the concept of learning outcomes to the students and also to present the programme learning outcomes to the students. This survey acted as the catalyst to prepare a presentation to students on the concept of learning outcomes and also to formulate the programme learning outcomes in a format suitable for presenting to students.

4.1. Formulating programme learning outcomes

Following the survey, the formulation of the degree programme learning outcomes for presentation to the students was undertaken. A first draft document was created and it consisted of nineteen learning outcomes. These learning outcomes were created after reviewing the following documentation:

- Learning outcomes used in the guidelines for accreditation of engineering undergraduate degree programmes by the [Institution of Engineers of Ireland \(2003\)](#).
- Learning outcomes used in the guidelines for accreditation of chemical engineering degree programmes by the [Institution of Chemical Engineers UK \(2005\)](#).
- Accreditation document submitted to the Institution of Engineers of Ireland by the [Department of Process & Chemical Engineering UCC \(2006\)](#). This was part of an application for full accreditation with the Institution.
- Accreditation document submitted to Institution of Chemical Engineers, UK by the [Department of Process & Chemical Engineering UCC \(2005\)](#). This was as part of an application for full accreditation with the Institution.

The draft document was then circulated to the staff within the Department who lectured on the degree programme and

1. How would you rate your level of confidence in being able to explain the concept of a learning outcome to another person?

Very confident Fairly confident Not sure Poor confidence Very poor confidence

Please comment _____

2. How would you rate your level of confidence in being able to write down the Learning Outcomes of your degree programme?

Very confident Fairly confident Not sure Poor confidence Very poor confidence

Please comment _____

3. How would you rate the session and document on Learning Outcomes?

Very useful Useful Not sure Not very useful Waste of time

Please comment _____

Fig. 5 – Questions 1, 2 and 3 of the questionnaire given to the students after the learning outcomes presentation.

a request for their feedback was made. The staff gave their input through written comments and face-to-face meetings. A second draft incorporating the input from staff was then produced.

The major features of the document are as follows:

- Definition of the learning outcomes concept and its usefulness.
- Statement of the degree programme learning outcomes.
- Description of how the individual modules and their assessment are related to the degree programme learning outcomes.
- Provision of a short section which tries to relate the achievement of the degree with careers within the core of process and chemical engineering and to other career opportunities.

This document was used as the basis for the creation of a PowerPoint presentation to be made to the first year and fourth year students. From the feedback received to the presentation, it was obvious that the first learning outcome was too broad and was consequently broken down into two learning outcomes, resulting in a third draft which consisted of twenty learning outcomes. A summary of the twenty programme learning outcomes for the BE degree in Process and Chemical Engineering is presented in [Appendix A](#).

5. Communicating with the students

As stated above, a PowerPoint presentation based on draft 2 of the learning outcomes document, was presented to the first year and fourth year students. The students were also provided with the document itself at the beginning of the presentation. At the end of the presentation, a short questionnaire was given to the students to evaluate if they had gained a better understanding of the concept of learning outcomes concept and of the degree programme learning outcomes. In addition, it was hoped to gauge their opinion on the benefit of this type of session to them. Questions 1, 2 and 3 of the questionnaire are presented in [Fig. 5](#). Analysis of the student

responses is now considered for both sets of students that were surveyed.

5.1. Responses from first year students

Twenty-six of the thirty first year students attended the presentation and were surveyed afterwards. Analysis of their responses to the questions is presented below, including a summary of the comments made by the students:

Q1. How would you rate your level of confidence in being able to explain the concept of a learning outcome to another person?

Quantitative data on the responses of the first year students to Q1 is presented in [Fig. 6](#). The key points emerging from the analysis of data are:

- 96% of students are confident of explaining the learning outcome concept.
- These data represent a major improvement in the understanding of learning outcomes and the degree programme learning outcomes where only 30% of the first year students expressed confidence when initially surveyed prior to the presentation.

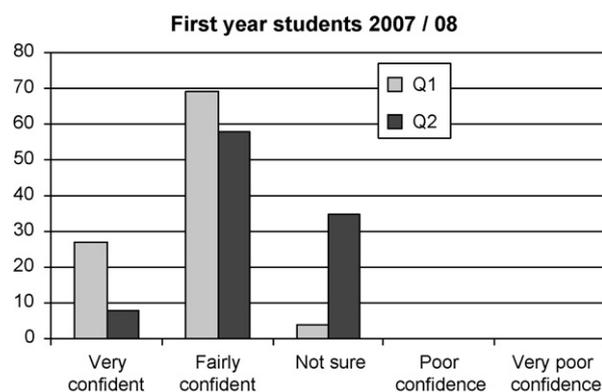


Fig. 6 – Responses of first year students to Q1 and Q2.

The student comments regarding Q1 can be summarised by the following typical student statements, e.g. they “have now more knowledge of the exact definition of a learning outcome” and “it is a lot clearer now after the session” and “it was made very clear in the presentation”. One student remarked that “it is a hard concept to grasp”.

Q2. *How would you rate your level of confidence in being able to write down the Learning Outcomes of your degree programme?*

The results of the data gathered on the responses of the first year students to Q2 are presented in Fig. 6 above. The major points emerging from the data are:

- 65% of students are confident that they can write down most of the learning outcomes of the degree programme while 35% are unsure. None have poor confidence.
- These data represent a major improvement in the understanding of the degree programme learning outcomes where only 30% of the first years students expressed confidence when initially surveyed prior to the presentation.

The student comments regarding Q2 can be summarised by the following typical student statements. The programme learning outcomes “were very well explained in the presentation” and “some may be more easily defined than others, some are still fairly unclear”. The reason why some are unclear is because the students are “only in first year” and “it is more likely that LOs become more apparent as you progress” through the degree programme. Overall, the first year students gained “a fairly good idea of what the learning outcomes of the course are”.

Q3. *How would you rate the session and document on Learning Outcomes?*

All students found the session beneficial with 65% rating it as very useful and 35% rating it as useful. It was felt that the session also gave the first year students an insight into second, third and fourth year. The students’ comments were very positive and can be summarised by the following typical student statements, e.g. the session “gave me a good insight into what a learning outcome is and what I’m expected to know when I finish my course” and “the session was very helpful as it gave us an insight into second, third, and fourth year”. This is a recurring comment by many of the students where the session gave the first students an overview of what the courses was all about and what they would be doing in subsequent years. Overall, many of the students were enthused by the session and one student remarked that the session was “extremely interesting and the outcomes were laid out in a clear manner”. Presenting LO’s to students therefore has a clear motivational effect as it makes clear to students exactly what they have to learn to succeed, through clearly stated academic expectations, thereby improving the chances of improving the quality of their education through a deep approach to learning (Ramsden, p. 125 & 80, 2003).

5.2. Responses from fourth year students

Only 11 of the 25 fourth year students attended the presentation and were surveyed afterwards. Analysis of their responses to the questions is similar to the first years and is summarised as follows:

- Question 1: 82% of students were confident of explaining the learning outcome concept. 18% were still unsure while none expressed poor confidence. This represents a major improvement on the initial survey prior to the presentation where 48% were confident, 33% not sure and 14% were

not confident. Student comments regarding Q1 state that the learning outcomes concept is “a simple concept once defined” and “from the presentation it is easy to understand what the term means”. However, another student stated that “it is a difficult concept to someone unfamiliar with learning outcomes”.

- Questions 2: 73% of students were confident that they could write down most of the learning outcomes of the degree programme while 18% were unsure and 9% had poor confidence. This represented a major improvement on the initial survey prior to the presentation where only 24% expressed confidence, 38% were unsure and 38% were not confident. The student comments demonstrated that they would be able to outline most of the learning outcomes in a general sense but not in the detail provided in the session.
- Question 3: a total of 10 of the 11 students found the session beneficial with half of these rating it as very useful and half rating it as useful. One student was unsure of the usefulness of the session. A number of the students commented that it would be beneficial to give this type of session to first year students. One student commented that “I found it useful to take a step back and find out what we’ve achieved in this course and its relevance to the working environment”. Another student commented that this type of exercise “is very useful for interviews and looking at areas apart from engineering”. This is a very valid comment as being able to express your achievements in terms what you can do and the skills you possess can very impressive at interview. Also, many of the learning outcomes achieved can be applied to other employments outside of chemical engineering.

6. Conclusions

An initial questionnaire survey of the undergraduate students in the Department of Process & Chemical Engineering in UCC clearly showed that the majority had a poor knowledge of the concept of learning outcomes and the programme learning outcomes for the BE degree in Process and Chemical Engineering. Some students had a perception of the programme learning outcomes, and this appears to originate from a first year module (PE 1003 Introduction to Process and Chemical Engineering), which provides a general overview of process engineering to first year students. Programme learning outcomes do exist in the Department accreditation documents submitted to IChemE and IEl, but it appears that these are not communicated to the students.

The initial survey acted as the motivation for taking the initiative to try to inform the students about the concept of learning outcomes and to create an awareness of the programme learning. This was undertaken by creating a document to inform the first and fourth year students about these two areas and also making a PowerPoint presentation to the students. This presentation was based on the document given to the students and outlined the concept of learning outcomes as well as surveying the programme learning outcomes of the degree and highlighted the modules in which these programme learning outcomes were achieved.

After the presentation, the students were surveyed to assess the impact of the presentation on them. The major impacts are as follows:

- It greatly improved their understanding of the concept of learning outcomes and the programme learning outcomes for their degree course.

- The students highly rated the presentation and stated that it was beneficial to them.
- Some fourth year students commented that this presentation would be very useful if given in first year.
- For the first year students, the presentation represented a “mapping out” of the whole degree programme in addition to communicating to them what they should achieve during their four years. It gave them a much clearer picture of what lay ahead for them in years 2, 3 and 4. It also gave them a much greater connection to the core discipline of chemical engineering.

The above findings are consistent with other publications that discuss the advantages of learning outcomes. In general, it is found that learning outcomes help to explain more clearly to students what is expected of them and thus help to guide them in their studies giving them increased motivation and a sense of purpose (Adam, 2004; Allan, 1996). Based on the above, it was decided that in future years the programme learning outcomes presentation and the explanatory documentation will be provided to the first year and fourth year students on an annual basis. The first years will receive this presentation as an integral part of the first year module PE1003.

Even though this paper is based on a small case-study and therefore it is not suggested that the findings are applicable on a wide scale to similar programmes, it is possibly true to state that some of the conclusions may be relevant to other engineering degree programmes. In particular, it is clear that it is important to formulate and communicate programme learning outcomes to students and to highlight the benefits that they can gain from this activity.

Acknowledgements

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Appendix A. Summary of programme learning outcomes for BE degree in Process and Chemical Engineering at University College Cork

A summary of the degree programme learning outcomes is presented in this appendix.

Twenty Learning Outcomes were created and they are presented below under eight headings.

A.1. (A) Knowledge and understanding of mathematics, science and core chemical engineering

1. To demonstrate an understanding of the mathematics which underpin chemical engineering.
2. To demonstrate an understanding of the sciences (of chemistry, physics, biochemistry, microbiology and biotechnology) which underpin chemical engineering.
3. To demonstrate an understanding of core chemical engineering, including.
 - (i) Creating and reading chemical engineering drawings (including P&ID diagrams).
 - (ii) Developing, applying and evaluating mass and energy balances in chemical engineering analysis.

- (iii) Application of fluid mechanics to solving chemical engineering flow problems.
- (iv) Application of thermodynamics to chemical equilibria and reactions, and in understanding and solving energy problems.
- (v) Application of heat and mass transfer theory in process analysis, such as heat exchangers and separation processes.
- (vi) Application of kinetics and reactor analysis in the design and performance evaluation of chemical and biochemical reactors.
- (vii) To describe and analysis the function of a variety of unit operations found in the process industries.
- (viii) Application of control theory in chemical process control and automation.

A.2. (B) Problem solving

4. To derive expressions and apply solutions for quantitatively solving defined problems in chemical engineering using a knowledge of the sciences, engineering sciences, technology and mathematics.
5. To identify, formulate, analyse and solve engineering problems.

A.3. (C) Social, environmental and economic context

6. To demonstrate an awareness of industrial health and safety issues and be able to suggest and implement technologies and procedures for protecting human health and safety.
7. To demonstrate an awareness of the need for environmental protection and the concept of sustainability and be able to suggest and implement technologies and procedures for protecting the environment and achieving sustainable living.
8. To demonstrate an awareness of typical legal requirements on personnel, processes, plants and products relating to health, safety and environment.
9. To calculate and explain process, plant and project economics.
10. To demonstrate an appreciation of the need for high ethical and professional standards, and how they are applied to issues facing engineers.

A.4. (D) Engineering design

11. To perform process design of unit operations.
12. To perform basic mechanical design of process system components and unit operations.
13. To design an entire process to produce a product with defined specifications.

A.5. (E) Practical/transferable skills

14. To apply the following skills:
 - (i) Computer software.
 - (ii) Communication.
 - (iii) Work effectively as an individual.
 - (iv) Work effectively in teams and multi-disciplinary settings.
 - (v) Project management.

- (vi) Laboratory/experimental skills.
- (vii) Lifelong learning.

A.6. (F) Working as an engineer in practice

15. To demonstrate:

- (i) Awareness of the application of chemical engineering skills to a variety of jobs and working environments.
- (ii) Application of chemical engineering skills in a real work setting.

A.7. (G) Research skills

16. To apply the following research skills:

- (i) Literature review and knowledge acquisition—to identify the current state-of-the-art in a particular research topic and to find knowledge and techniques that are useful to the implementation of a research project.
- (ii) Apply statistical techniques in research, in particular, experimental design and establishing significant correlations.
- (iii) Conducting experimental/quantitative research work.
- (iv) Data analysis and interpretation.
- (v) Communication of research results and conclusions.
- (vi) Managing research projects: planning, tasks, time, people and resources.

A.8. (H) Additional knowledge and skills

17. To demonstrate:

- (i) Understanding of knowledge in bioprocessing.
- (ii) Ability to deploy engineering methods to analyse and design the respective units and systems within this area.

18. To demonstrate:

- (i) Understanding of knowledge in one of specialist streams of pharmaceutical/food and bioprocessing/supply chain engineering and management.
- (ii) Ability to deploy engineering methods to analyse and design the respective units and systems within those areas.

1. To implement validation procedures and documentation.
2. To demonstrate an awareness of business knowledge and skills in the successful commercialisation of products and services in a market economy.

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