Assessing Learning Outcomes in Engineering Education: An e-Learning based approach

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ABSTRACT
This research project addresses the assessment of Learning Outcomes using e-learning, in different levels of Engineering Education. Accrediting e-learning as an assessment tool that can be applied independently of the learning pathways may contribute to the achievement of recognition of prior learning and mobility of students. This paper will provide a comparative analysis of the LOs integrated in different frameworks, including the European Qualification Framework (EQF), ABET and EURACE, using the revised taxonomy of Bloom. It is intended by this analysis to identify crucial LOs in Engineering Education and mapping them into a general qualification framework like EQF. This analysis will also focus on proposed assessment strategies of the identified LOs, as found in literature and will constitute the initial ground to establish a model that aligns LO in Engineering Education with assessment strategies based on e-learning.

Keywords
Assessment of learning, Learning Outcomes, e-learning, Engineering Education

1. RATIONALE
Since the last half of the 20th Century, the World has been experiencing rapid transformation in the field of Education, led by the changing Knowledge Society. Higher and Continuing Education have been most affected by this transformation, adapting to the demand for new skills of the labour market and at the same time corresponding to the needs of an increasing number of students. The Global Economy created opportunity and need for the mobility of students and workers, demanding better recognition of qualifications and increasing competitiveness in this field. One visible effect of this transformation is the shift from a content based approach in Education to an approach centred on the student which includes the definition of Learning Outcomes (LO). This approach is underpinning the development and implementation of most European Education policies, at international and national level. In Europe, Higher Education Institutions (HEI) and Continuing Education Institutions (CEI) are redefining programmes in terms of LO, harmonizing them with national, international and sector specific frameworks of qualifications that are also based on LO. In this context, the assessment of LO becomes a crucial process for the Educational System. Measuring the real Learning Outcomes of the student against the intended ones, using assessment strategies that are appropriate for the situation should be one main concern of HE and CE Institutions.

Another major revolution in our society has been the introduction of Information and Communication Technologies (ICT). The use of ICT applied to Education, has been increasing and its use creates new opportunities for teaching, learning and assessment and has huge potential as an answer to some of the current challenges of Education.

This research project is placed in the intersection of these two areas and will address the assessment of Learning Outcomes using e-learning, in different levels of Engineering Education. Accrediting e-learning as an assessment tool that can be applied independently of the learning pathways may contribute to the achievement of recognition and mobility of students and to the creation of a flexible Education System. This paper will focus on the first stage of the research that aims at collecting background information to direct research. It will provide a comparative analysis of the LOs integrated in different frameworks, including the European Qualification Framework (EQF) [1], ABET [2], CDIO [3] and EUR-ACE [4]. It is intended by this analysis to identify crucial LOs in Engineering Education and mapping them into a general qualification framework (QF) like EQF. This analysis will also focus on proposed assessment strategies of the identified LO, as found in literature [5]. This integrated analysis will constitute the initial ground to establish a model that aligns LO in Engineering Education with assessment strategies based on e-learning.

2. The importance of the Learning Outcomes approach
The importance of LOs in Europe emerged when they were introduced as part of the major reforms in Education in Europe. These were aiming at improving mobility, recognition and employability by increasing the proximity between education delivery and the labour market needs [6]. Even though LOs are sometimes present in national policy, the transnational policy development is particular important in the current LOs approaches. The Bologna Process, the Copenhagen process, the development of the European Qualification Framework as well as the initiatives related with the recognition of prior learning are examples of LOs approaches in policy, in different contexts of European Education.

This increasing importance of Learning Outcomes for defining and guiding Education, Training and Lifelong learning strategies
becomes clear when analyzing published documentation. LOs are present in the field of pedagogy but also in strategy and policy papers, at national, international and institutional levels. Not only the contexts are diverse but also there is a multitude of functions and roles attributed to LOs. LOs are a central piece in QFs, award of credits, quality assurance, structuring curricula, learning plans, key competences for life, communication with employers, modernizing education and training, and others.

This variety of roles of LOs and contexts to which they are applied makes it difficult to have a uniquely accepted definition. For the purpose of this paper, the definition proposed by the EQF will be used: “a statement of what a learner knows, understands and is able to do on completion of a learning process” [7]. LOs have a prominent role in Education, having a direct impact on curricula and pedagogy, shaping what and how people learn. As stated by Stephen Adam in his report “Using learning outcomes” [6], LOs have application at three levels:

- Local (individual institution): for course units, programmes and qualifications
- National: for qualification frameworks and quality assurance regimes
- International: for wider recognition and transparency purposes.

For the purpose of this work, the relation between LOs and QFs is particular important. LOs have a key role in developing national and international QFs, a process that should involve different stakeholders and that should be negotiated and agreed. LOs have an important role making qualifications clear and easily understood by all stakeholders. They separate the qualifications from the learning process and centre it in the achievements of the Learners, in the profile of the workers.

In this context, for this paper one more level of impact of the LOs will be considered, transversal to the three referred above, that is the Sector level. In the Engineering sector there are several initiatives worldwide, coming from professional and educational institutions that are using LOs to structure programs, qualification profiles and accreditation procedures. Some of these will be discussed below.

3. FRAMEWORKS BASED ON LEARNING OUTCOMES IN ENGINEERING

3.1 The European Qualification Framework, EQF

The European Qualification Framework was adopted in 2008 by the European Parliament and Council [1] as a common device to translate and compare qualifications across Europe. Even though is not exclusively for the area of Engineering, is important for this research project. This framework, based on competences and learning outcomes should provide a common reference for recognition and the transferability of qualifications at all levels of Education. European countries were invited to relate their qualifications systems to EQF by referencing, in a transparent manner, their qualification levels to the levels set out by EQF. EQF includes eight reference levels based on Learning Outcomes that describe what a learner knows, understands and is able to do. For the purpose of this paper, only levels from 6 and 7 will be considered since these are the levels that address the first and second cycles of Higher Education. The LOs presented are general and can be applied to any sector or area of Education.

3.2 ABET (ACCREDITATION BOARD FOR ENGINEERING AND TECHNOLOGY)

“ABET, Inc.”, formerly named Accreditation Board for Engineering and Technology, developed a system for accreditation of engineering programmes that includes 9 criteria. The third criterion describes the programme outcomes that students should attain when they graduate at baccalaureate level [8] (ABET a to k):

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
(d) an ability to function on multidisciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

For Master level, LOs must be defined by the institutions but must fulfill the general criteria here indicated plus the specific outcomes of the masters’ level and specialization area.

3.3 EUR-ACE: Framework Standards for the Accreditation of Engineering Programmes

The EUR-ACE is a system that aims at developing a framework for the accreditation of engineering degree programmes in the European Higher Education Area (EHEA) [4]. It intends to accommodate the diversity of existing programmes, allowing the comparison of the educational qualifications and promoting the mobility of engineering graduates. The EUR-ACE system describes the requirements of graduates using programme Learning Outcomes, both for first and second cycle. As with ABET and other accreditation frameworks, EUR-ACE describes the LO at a non-subject specific level and does not prescribe pedagogical methods to obtain the LOs. The Programme outcomes of the EUR-ACE system are distributed among six categories:
• Knowledge and Understanding;
• Engineering Analysis;
• Engineering Design;
• Investigations;
• Engineering Practice;
• Transferable Skills.

These six categories apply to both first and second cycle programmes but the descriptors are different for each level. The second cycle graduates should include LOs described for both levels. The system provides an explanation of what is meant by each of the categories and provides a detailed list of LOs. It is more detailed than the ABET criteria since it includes 22 LOs descriptors just for the 1st cycle of Engineering programmes.

3.4 CDIO: Conceive – Design – Implement – Operate

The CDIO Initiative (Conceive, Design, Implement, Operate) can be considered a sector framework for Engineering but specifically for the creation of undergraduate Engineering programs. It was developed with input from different stakeholders from the Academia, from the industry and from the profession [3]. It intends to be a universal system for engineering schools. It was originally a joint effort of three organizations in Sweden, the Royal Institute of Technology (KTH), the Linköping University and Chalmers University of Technology, and of the Massachusetts Institute of Technology of the USA, but is now used by several schools around the world. The CDIO proposes a new vision for Engineering Education based on the principle that “engineering graduates should be able to: Conceive – Design — Implement — Operate complex value added engineering systems in a modern team-based engineering environment to create systems and products”.

The CDIO Syllabus [9] is a tool to establish program goals, consisting of a comprehensive and detailed list of Learning Outcomes for Engineering Education developed through a systematic process described by several authors ([10], [11], [12]). The syllabus includes more than 400 descriptors, distributed by the following 4 categories:

1. Technical knowledge and reasoning
2. Personal and professional skills and attributes
3. Interpersonal skills: teamwork and communication
4. Conceiving, designing, implementing and operating systems in the enterprise and societal context

The complete version of the syllabus is one of the most valuable contributions of CDIO when compared with other Engineering or general QFs. Although very detailed, the LOs described are not subject specific and it is up to each institution to define LO at subject level.

3.5 COMPARISON OF LEARNING OUTCOMES OF DIFFERENT SYSTEMS

One of the aims of this research was to establish some common ground in the description of LOs in Engineering Education. This will facilitate the development of a general model that relates e-assessment methods and Engineering. By researching literature, different studies were found that compare two or more systems referred in this paper. In the CDIO website [9], the syllabus in topical format proposes a matrix of correspondence between CDIO and ABET ask criteria. Also, it is possible to find conference papers that propose correspondence between CDIO and EQF [13], CDIO and EUR-ACE [11]. A conference paper by Feyo de Azevedo [8] presents comparisons between different qualification descriptors in the area of engineering, including a matrix of correspondence between EUR-ACE and EQF, ABET and CDIO. There are, however, some discrepancies between the matrices of correspondence found in different sources.

For this paper a combined analysis was performed, feeding from the different comparisons found, intending to provide a global vision of Learning Outcomes in the engineering sector. Some of these results are presented in Table 1. It was concluded from a preliminary analysis that these matrices are, to some extent, subjective since there are considerable differences in scope, focus and detail in the various descriptors. The CDIO descriptors are highly detailed so most comparisons relay on the second level of detail of the CDIO syllabus. However, a more deep analysis shows that the correspondence should be done at lower levels.

Table 1 – Matrix of comparison of LO in different QF

<table>
<thead>
<tr>
<th>CDIO</th>
<th>ABET</th>
<th>EUR-ACE 2nd cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>A</td>
<td>1.1</td>
</tr>
<tr>
<td>12</td>
<td>A</td>
<td>1.1, 5.1, 5.2, 5.3</td>
</tr>
<tr>
<td>13</td>
<td>K</td>
<td>1.3, 2.4, 4.4, 5.1, 5.2, 5.3</td>
</tr>
<tr>
<td>21</td>
<td>E</td>
<td>2.1, 2.2, 2.3, 2.4, 2.5, 2.3</td>
</tr>
<tr>
<td>22</td>
<td>B</td>
<td>4.1, 4.2, 4.3, 4.4</td>
</tr>
<tr>
<td>23</td>
<td>I</td>
<td>1.4, 3.3, 3.5</td>
</tr>
<tr>
<td>24</td>
<td>I</td>
<td>3.2, 4.5</td>
</tr>
<tr>
<td>25</td>
<td>F</td>
<td>6.3</td>
</tr>
<tr>
<td>31</td>
<td>G</td>
<td>6.1, 6.6</td>
</tr>
<tr>
<td>32</td>
<td>H</td>
<td>6.2</td>
</tr>
<tr>
<td>33</td>
<td>H</td>
<td>3.2</td>
</tr>
<tr>
<td>41</td>
<td>J</td>
<td>5.4, 6.3</td>
</tr>
<tr>
<td>42</td>
<td>C</td>
<td>5.4, 6.4</td>
</tr>
<tr>
<td>43</td>
<td>C</td>
<td>2.2, 2.3, 2.4, 3.1, 3.2, 3.3</td>
</tr>
<tr>
<td>44</td>
<td>C</td>
<td>1.4, 2.2, 2.3, 2.4, 3.1, 3.2, 3.3</td>
</tr>
<tr>
<td>45</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>C</td>
<td></td>
</tr>
</tbody>
</table>

As an example, the LO of CDIO 1, “Knowledge and understanding of the scientific and mathematical principles underlying their branch of engineering” it is matched to ABET (a) “an ability to apply knowledge of mathematics, science, and engineering” by Crawley. The same CDIO 1.1 is matched by Malmqvist to the EUR-ACE 2nd cycle 1.1 “An in-depth knowledge and understanding of the principles of their branch of engineering” [11]. If the LOs in the first pair are very similar, the second match is not as defensible. The same 1.1 EUR-ACE descriptor is matched by Azevedo to the EQF 7.1.1 and 7.1.2 that are “Highly specialized knowledge, some of which is at the forefront of knowledge in a field of work or study, as the basis for
original thinking and/or research” and “Critical awareness of knowledge issues in a field and at the interface between different fields”. Again, this matching pair seems to be more aligned with the one by Crawley than by Malmqvist.

This comparison and matching exercise led to the conclusion that it would be very complex to produce a matrix that aligns the LOs in EE as defined in these frameworks. Even using the CDIO Syllabus as a common language for the comparison turned out to be a difficult task. Although the CDIO has the higher level of detail, the LOs descriptions are still quite complex. To proceed with this line of research it was necessary to find a common language for the LOs.

3.6 The revised Bloom’s Taxonomy as common language

The main problem of this component of the research was how to go from the high level LOs of the QFs to specific methods for the assessment of LOs. After the impossibility of using CDIO syllabus as a common language, literature research led the author to adopt the revised version of Bloom’s Taxonomy by Anderson et al. [14]. This revised version proposes a taxonomy with two dimensions: knowledge and cognitive process. The knowledge dimension includes four types of knowledge (factual, conceptual, procedural, meta-cognitive) that are then detailed in eleven subtypes. The cognitive dimension includes nineteen processes that are organized in six categories (remember, understand, apply, analyze, evaluate, create). Authors propose that this two dimensional taxonomy defines a matrix where the intended LOs can be positioned providing a “map” that can then be used to harmonize them with learning activities and assessment strategies.

For the project here presented, this taxonomy seemed to be the adequate tool to be used as a common language. Both dimensions were used to break down the LOs of the QFs by matching them to the corresponding type of knowledge and cognitive process. Take as an example ABET(c):

- **Knowledge**: The ability to design a system, component or processes indicates PROCEDURAL KNOWLEDGE including “knowledge of subject-specific skills and algorithms” and “knowledge of subject-specific techniques and methods”. This part of the LO also indicates the need for CONCEPTUAL KNOWLEDGE since to design a system and component it is necessary to have knowledge of principles, theories and models.

- **Cognitive**: This LO has a clear connection with the category CREATE, in particular with the process PLANNING since it is about designing something. The more complex part is related with meeting the needs within the constraints. This can be related with APPLY/IMPLEMENTING since can be considered a unfamiliar task. Also, it has components of UNDERSTAND, including INFERRING since it includes reaching a conclusion (the final design) from existing information (about the needs and constraints. Also, EVALUATE, in both components of CHECKING and CRITIQUING since it is necessary to verify is the reached design is adequate to the existing circumstances.

4. E-Assessment of LO in Engineering Education

E-Learning is spreading in all levels of Education, in particular in Higher and Continuing Education, creating opportunities for innovation. E-learning, due to its flexibility, scalability and personalization, might give an important contribution to the widespread of the LOs approach. Assessment using e-learning is still in early stages of development. However there is already considerable experimentation in different types of formative and summative assessment. This component of the research project research will be focusing in establishing a model that relates existing on-line assessment practices to the LOs approach, in particular the LOs identified in the QF described above but also to programme and course level.

Assessment and e-learning are two distinct areas receiving a lot of attention in the field of Education. From reviewing existing literature ([15], [16], [17]) we find that both areas are rapidly evolving and contributing for the development of e-assessment. The main aim of this research is to contribute to increase the contribution of e-learning in improving assessment of LO in the field of EE. Because technology changes rapidly, this work won’t focus on particular technologies but on e-learning tools and strategies that can be used to perform assessment of student learning. For the purpose of this paper, the term Computer Assisted Assessment (CAA) will be used and the definition adopted will be the one proposed by Bull [16], the common term for the use of computers in the assessment of student learning, including delivery, mark and analyze assignments or examinations. Other terms are used in this area, with considerable differences of meanings: computer based assessment, computer based testing, computerized assessment, web based assessment, e-assessment, online assessment and several others.

The introduction of learning technologies brings new opportunities for teaching, learning and consequently to assessment, since it introduces new elements not available in a more traditional context. CAA can include different types of assessment, as long as computers are used during the process. As Bull recommends, before introducing CAA an evaluation of the assessment methods that can be more effective and efficient for the intended LOs can be very useful. There isn’t a single method that suits every type of LOs.

4.1 Computer assisted assessment methods – a practical study

In the beginning of this research project, as a starting point for discussion and analysis, a list of CAA methods was collected from literature. The first version, which included more than thirty methods, was analysed by e-assessment experts aiming at establishing some criteria in the selection and structure of the tools and methods identified. Even though it is not intended to define a closed list of e-assessment, it was important to establish a starting point that could be worked among a larger community.

A practical study was implemented with a group of stakeholders, during a workshop in an e-Learning conference to address the following questions:

- Can all type of Learning Outcomes be assessed using on-line tools?
• How do we assess EQF Learning Outcomes using on-line tools?
• Which tools can be used for each type of Learning Outcome

To support the group activity, some background documentation was distributed, which included the Learning Outcomes of EQF, from levels 5 to 8, and a smaller selection of on-line assessment tools: chat, forum, e-mail, computer-based testing, paper-based testing, assignments, game-based learning, role play, simulations, peer assessment, e-portfolios, websites / media, and wikis. Participants were involved in a group activity aiming at establishing a matrix of correspondence between the LOs of EQF and the proposed tools. At the end of the workshop, there was no consensus in a final version of the matrix, i.e., in relating EQF LOs and CAA methods.

The main conclusion of this workshop was that it is difficult to match assessment and LOs defined at a higher level. Again, using Bloom’s revised taxonomy seems to be a good solution for this problem. Another important conclusion was concerned with the selection of assessment methods, some of which were not considered as such but only tools that are used to deliver the assessment process. This disparity of criteria in the selection process was already detected when analysing literature. Being assessment such a complex issue in education, deeply depending on the stakeholders, it is difficult to simplify and reach a sample of methods that is universally accepted.

This workshop was a starting point for the research, a preparatory study. Even though it is not central to the research, the conclusions contributed to clarify some aspects and problems related with the application of existing qualification frameworks. The level of abstraction of the descriptors of L0s make QF difficult to implement in concrete situation. This research intends to develop a model and tools to overcome this obstacle.

4.2 Assesment and Bloom

As a result of the described workshop, there was the need to find elements that would bring meaning to the correspondence between assessment methods and LOs: LOs needed to be broken down in measurable and assessable components; assessment methods needed to be clarified and organized. For the first problem, a possible solution was again the use of Bloom’s revised taxonomy. For the second problem, a similar solution has been adopted. Current work has been focusing on defining general assessment methods by researching literature ([18], [19], [14]) and relating them to types of L0s. Brown et al. propose a list fourteen general methods of assessment that can then be described using Bloom’s action verbs.

5. Conclusion and future work

The analysis of the LOs in the presented frameworks revealed that they have different scope, focus and detail. This is probably due to the different aims they have but also the differences behind their development. These differences increase the difficulty of mapping and relating the frameworks between them. None of the frameworks analyzed can perform the role of the “exchange currency” between them.

From the perspective of assessment, the attempt to match methods with the LOs of the QFs was again a difficult task. The complexity and density of high level LOs does not allow a clear correspondence with assessment methods.

The first approach to both perspectives of this research, indicate the need to use a common language for breaking down high level LOs into lower level components. Bloom’s taxonomy and corresponding action verbs may be used to translate LOs in measurable units that can be assessed.

Undergoing and future work will use Bloom’s verbs to analyse LOs at different levels: QF, programme and course level. Also, assessment tools will be matched to specific types of knowledge and cognitive processes, as defined in Bloom’s revised taxonomy. After this stage, the intention is to propose a final model that suggests how LOs in EE may be assessed using computer assisted methods and apply it to case-studies at different levels.

6. REFERENCES

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