Assessment of Student Learning Outcomes in Engineering Education and Impact in Teaching

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Abstract

It is presented a conceptual model that aligns Learning Outcomes (LO) in Engineering Education (EE) with assessment strategies based on e-learning. The research problem was made taking into account three areas of research: Assessment, Engineering Education and e-Learning. The work managed to verify to what extent e-assessment methods may be used to measure intended Learning Outcomes of Engineering courses. The study was planned to facilitate the curriculum design, the teaching delivery planning, the recognition of e-learning courses and to improve definition of assessment tools. In general terms, the approach chosen was to develop a model that matches various common assessment methods to measure the achievement of the main Learning Outcomes (LO) in the field of engineering. This means that it should be possible for a teacher to define the intended LO of the engineering course and, considering this definition, to write proper and possible adequate assessment methods. The work done in the study proposes a conceptual model ALOE (Assessment of Learning Outcomes in Engineering). ALOE was used to describe the Learning Outcomes and the proper assessment and to achieve alignment between these two components of the educational process. The impact in teaching that resulted from the application of ALOE is evaluated based in some case studies. The impact is presented in terms of curriculum organization, assessment methods, teaching activities and learning evaluation results.

Keywords: *Learning Outcomes, Assessment, Engineering Education, E-learning, Teaching.*

1. Background and Field of Study

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. As Peter Drucker [1] explained in 1996, in this new society access to work is only gained through formal education and not acquired through apprenticeship. Almost two decades have passed and this is already what is happening in some parts of the World. Education and schooling have become a major concern for the society and it is a priority in national and transnational policies. Higher Education (HE) and Continuing Education (CE) have been most affected by this transformation, adapting to the demand for new skills of the labor 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. The labor market demands more workers qualified and updated. All this generates pressure towards a quality based approach in all Education providers, as Drucker predicted.

One visible effect of this transformation is the shift from a content based approach in Education to an approach centered on the student and what he/she has learned and achieved, the learning outcomes (LO). This approach is underpinning the development and implementation of most European Education policies at international and national levels [2], [3], [4]. In Europe, higher education (HE) institutions and continuing education (CE) institutions are redefining programs in terms of LO, harmonizing them with national, international and sector level frameworks of qualifications that are also based on Learning Outcomes. Several projects and initiatives are working towards the definition of LO, specific and transversal that can be used as a common reference. Learning Outcomes are also becoming fundamental for structuring the standards and guidelines of quality assessment of HE and CE institutions. In this context, the assessment of LO becomes a crucial process for the educational system. Measuring the real LO achieved by students, 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 and to e-learning 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. The change to the digital media has impact on the availability, reusability, accessibility and cost of learning resources, complemented by the communication and networking potential of the Internet that takes education to a global level. E-learning is promoting change and innovation in different aspects of Education including pedagogy, technology, organization, accessibility, and flexibility among others [5]. It is a complex and multidisciplinary area and, given its impact, it is important that e-learning research be informed by evidence [6]. Current literature reviews in this area indicate that e-learning approaches to assessment lack pedagogical framework and most research describes implementation studies at course level [7].

The present research intends to contribute to establishing a pedagogical framework for the implementation of e-assessment in Engineering Education (EE). Finally, assessment is a crucial process of education and is seen by current trends as part of the learning process and not as a separate event. Assessment of student learning encourages involvement of student and provides feed-back to the student and the teacher [8]. It has an important role in validation and certification and is deeply related with quality issues.

This paper is placed in the intersection of these three fields: learning outcomes, assessment of student's learning and e-learning. It is focusing in HE and more specifically, in EE. The purpose of this study is to contribute to accrediting e-learning as an assessment delivery tool that can be applied independently of the learning pathways. It intends to contribute to the achievement of recognition and mobility of students and to the creation of a flexible Education System. In general terms, the approach chosen was to develop a model that matches specific e-assessment methods to measure the achievement of the main LO in the field of engineering. Again in general terms, this means that it could be possible for a teacher to define the LO of his online course and from this definition to have an indication of the assessment methods he might consider using. Formally, this problem is defined as "To what extent assessment methods may be used to measure intended the achievement of LO in engineering education?"

Given this problem, it was necessary to recognize that there were a wide variety of engineering schools, engineering programs and engineering courses. There are also different qualification frameworks that also use LO. So, the first challenge was how to select the LO that were going to be used for the purpose of the research. The same problem existed in relation to assessment. Assessment tasks are usually defined at course level, even though some examples can be found at a higher level. Again, there is a considerable variety of assessment tasks, some of them deeply embedded in the structure of the course or unit, i.e. at assessment tasks are highly contextualized. So, the first stage of the development of the conceptual model focused on the definition of the two main components: LO and assessment. The four questions addressed were:

Q1) Which LO in the field of Engineering are relevant and should be considered?
Q2) Which are the online assessment methods that should be considered?
Q3) What type of intended LO can be measured by assessment methods?
Q4) Is it possible to propose specific assessment strategies for each type of LO in EE?

2. ALOE Conceptual Model

The model for the alignment of intended LO in EE was developed from the concept of alignment defended by different authors [9], [10], [11]. In terms the alignment component, what is defended is that the LO of a course or unit should be used to define the teaching and learning activities, ensuring these will address the same LO. The same applies to the assessment tasks. To ensure the validity of assessment in relation to what is intended from the course, it is necessary that the outcomes measured by the assessment tasks are the same as the intended ones. The initial step to approach the problem was to identify and define the different components of the problem: the two variables, intended LO in EE and assessment methods; and the link between them that is the alignment question.

The main tool used for developing this conceptual model was the revised version of Bloom's Taxonomy [10]. This tool, designated in this paper as matrix rBloom (Table 1), is in fact an alignment matrix for LO, teaching and learning activities and assessment. However, for the current research project the adopted matrix assumed distinct functions: describe and classify the LO in the EE in a way that facilitates comparison between different levels and different sources; describe the assessment methods and e-assessment tasks; align the LO with the assessment methods.

Table 1 – Taxonomy Table by Anderson et al

Knowledge dimension	Cognitive dimension					
	1. Remember	2. Understand	3. Apply	4. Analyze	5. Evaluate	6. Create
A. Factual						
B. Conceptual						
C. Procedural						
D. Meta-cognitive						

The conceptual model suffered several iterations resulting from small implementations. The final version of the ALOE model was defined as a sequence of operations. The LO in EE at the qualification level are transduced to the EE program level using the rBloom approach. From the program level the LO at course level are defined using the same method. Finally the assessment tasks are aligned with the LO of the course level using the rBloom based method. It is clear in this sequence of operations that the revised version of Bloom's taxonomy is the main tool that will be used to achieve the stated goals of this work. Every LO from the ABET and EUR-ACE were described using the rBloom matrix. Each LO from the courses that were part of the case studies was described using the same tool. Also, an rBloom matrix was produced for each assessment method, mapping assessment to the cognitive processes and types of knowledge, based on the description of the methods found in literature research. A total of forty matrixes were produced for categories and general assessment methods. This set of matrixes is the actual alignment instrument of the conceptual model. They represent the standard against which the LO matrixes of the case studies were compared to produce aligned assessment strategies or to verify current alignment.

3. Learning Outcomes in Engineering Education

The first research question of this paper was how to select and describe LO in the field of EE that were going to be studied. On one hand, there was a need to use LO that could be generally accepted as a reference and that would capture the essence of EE. On the other hand, it was necessary to have LO that were specific and detailed enough to be workable, to be related with specific assessment methods. The qualification frameworks of Engineering have adopted LO as the qualification descriptors. It was decided to adopt a top/bottom approach, starting by using the LO defined by the Qualification Frameworks (QF) of the sector. This decision was important to ensure the validity of the application to the field of EE, as long as it was possible to maintain the link between LO defined at a lower level (program, course) to the QF. Two professional qualification frameworks (QF) were analyzed and described using rBloom. These are the most accepted internationally that are EUR-ACE and ABET and both are based on learning outcomes. This decision was also taken by the AHELO-TUNING project [12].

3.1 ABET: Accreditation Board for Engineering and Technology

"ABET, Inc.", formerly named as Accreditation Board for Engineering and Technology until 2005, is an accreditation institution for engineering programs. In 1996 ABET started to change the accreditation process that was formerly based on institutional inputs to an outcomes-based system [13]. This system is composed of nine intended to assure the quality and improvement. The third criterion describes the eleven program outcomes that students should attain when they graduate at bachelor level and are known as "ABET a to k". The program outcomes are the following [14]:

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 lifelong learning
j) a knowledge of contemporary issues
k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Each programme accredited by ABET was described using the main tool of the conceptual model, the revised version of the taxonomy of Bloom. An example is found below, in Table 2.

Table 2. Example of analysis of ABET LO using rBloom

ABET a)	An ability to apply knowledge of mathematics, science and engineering
The analysis of this LO identifies a category of cognitive processes: APPLY. However it was considered that in order to apply the student will need to REMEMBER and UNDERSTAND. There are no clues indicating specific processes which are consistent with a LO at the level of QF. In terms of knowledge, there is no clear indication of types or subtypes so it was chosen to include the ones that are usually associated with the identified cognitive categories: FACTUAL and CONCEPTUAL. The template provided by Spurlin at al supports this classification of the LO. It identifies the necessary knowledge as general principles, theories, concepts and formulas. This clearly includes both factual and conceptual knowledge. In terms of cognitive processes, the term used is associated with applying. However, as Spurlin et al describe, to apply the student will need to define and describe. These may be classified in part as remember (recalling) and understand (interpreting, summarizing). The student will also need to explain (understand) and demonstrate, that can be classified as explaining and summarizing.	
Knowledge type	Factual Conceptual
Cognitive process	Remember: recalling Understand: interpreting, summarizing, explaining

3.2.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 programs in the European Higher Education Area (EHEA) [15]. It intends to accommodate the diversity of existing programs, allowing the comparison of the educational qualifications and promoting the mobility of engineering graduates. The EUR-ACE system describes the requirements of graduates using program 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 LO. The program outcomes of the EUR-ACE system are distributed among six categories:

1. Knowledge and Understanding;
2. Engineering Analysis;
3. Engineering Design;
4. Investigations;
5. Engineering Practice;
6. Transferable Skills.

These six categories apply to both first and second cycle programs (bachelor and master levels) but the descriptors are different for each level. The second cycle graduates should include LO described for both levels. The system provides an explanation of what is meant by each of the categories and provides a detailed list of LO. It is more detailed than the ABET criteria since it includes twenty two LO descriptors just for the 1st cycle of Engineering programs. Each category of LO was described using the Bloom revised taxonomy. An example of this analysis is represented in Table 3.

Table 3. Example of LO of EUR-ACE described using rBloom matrix

EUR-ACE 1	Knowledge and understanding
The description of this LO uses the terms knowledge and understanding that indicate two main categories of cognitive processes: remember and understand. The description does not give indication of the specific cognitive processes. Additionally there are indications about other processes. Coherent knowledge is related with analysis and specifically with organizing knowledge. Critical awareness is related with criticising.	
Knowledge type	Factual Conceptual
Cognitive process	Remember Understand Analyze: organizing Evaluate: criticising

As can be deducted from the analysis made, exemplified in the precedent table, it is concluded that the classification of the EUR-ACE competences for each EE program can be applied using the tool proposed based on the ALOE model. Consequently, in an analogous procedure of the ABET examples and tests, the LO of the

EUR-ACE accredited programs are also capable of being used to align the LO of the programs and of the courses with proper assessment methods.

4. Assessment Methods Considered

The second research question of this paper was concerned with identifying and selecting the assessment methods to integrate the model. Early exploratory research in this field revealed some obstacles to reach the intended goal. Most of the published papers related with assessment descriptive case studies of the implementation of one particular type of assessment. Literature reviews on assessment [7], [16], [19] were not focused on specific methods or strategies but on logistical or pedagogical issues. It was not possible to find a systematization of e- assessment methods that would contribute to answering the second research question or to derive it from. These reflections on e-assessment led to more profound reflections on the nature of assessment and the research on this subject took some steps back some steps back. It was necessary to systematize some knowledge about assessment. The work of Brown, Bull and Pendlbury was of great help for producing a working list of general assessment methods, adapted from the work of Brown et al [20]. For the purpose of this research and specifically for the development of the model, six general categories of assessment methods were identified:

a) Multiple choice questions (MCQ)
b) Short answer questions (SAQ)
c) Essays
d) Practical case
e) Problems
f) Reflective practice

It was considered that these categories were to general to provide information for the alignment with the LO. It was necessary to add detail and specificity to the assessment. The categories were further analysed and detailed. A total of thirty seven assessment methods were identified and described in terms of knowledge and cognitive processes. Table 4 provides an example of the description of an assessment method using rBloom taxonomy.

Table 4 – Example of the description of an essay question

Essay 06	Discuss
The student is asked to discuss a given fact or statement. This type of essay may involve describing the context, explaining the statement, comparing with other views, analyzing, evaluating the perspective.	
Knowledge type	Factual Conceptual
Cognitive process	Remember: recalling Understand: interpreting, explaining, summarizing Analyze: differentiating, organizing, attributing Evaluate: criticising

In terms of the assessment methods and practices, the definition was also derived from literature. From the initial analysis, it was decided to drop the idea of assessment methods and replace it by assessment methods that could be implemented using learning technologies or assessment practices. This decision had consequences in terms of alignment, since it was now being approached from the perspective of general assessment methods. If the alignment was reached between the LO and the general assessment methods, it was then possible to define implementation strategies using assessment tasks. After reaching a classification system for the assessment methods, the following step was to associate to suggest implementation strategies using assessment practices.

Table 5 - Suggestion of implementation of assessment methods using learning tools

	MCQ	SAQ	Essays	Practical case	Problems	Reflective
Animation				x	x	
Audio			x			x
Chat discussion				x	x	x
Computer based test or exam	x	x	x			
Concept maps			x	x	x	x
Diagram			x	x		
Discussion forum		x	x	x	x	x
e-portfolio						x
File upload		x	x	x	x	x
Game					x	

Remote lab			x		
Simulations			x		
slideshow	x	x			
Video		x	x		x
Virtual lab			x		
Wiki		x	x	x	

From the analysis of Table 5 it can be concluded that these are suggestions for possible use of different types of learning tools that could be assessed by different types of methods. The justification for this match is based purely in practices and in existing tasks derived from literature research and from the case studies analyzed.

5. Alignment of LO and Assessment

The concept of aligning learning outcomes (LO), learning activities and assessment is explored by several authors [9], [10], [24], [27]. As Biggs explains this means that the teaching methods and assessment tasks should be aligned with the learning activities expressed by the intended or desired learning outcomes (LO). In the work of Bloom et al [24], the concept of alignment is also present. In their view, the educational goals should be used to shape the curriculum, guide instruction and provide specifications for the definition of evaluation instruments, techniques and methods. For each class and sub-class the taxonomy provides examples of questions to assess that specific LO. In the revised version of the taxonomy, Anderson et al have a practical approach to the concept of alignment. In this work, alignment is the level of correspondence between objectives, instruction and assessment. As already referred, this was the tool chosen for this work both for the definition stage but also, for the alignment component.

The conceptual model ALOE [28], proposes the alignment of assessment with LO by overlapping the rBloom matrixes produced and looking for matching cells. Even though this is an apparently simple procedure, several issues were found related with the application of the model. When matching Bloom's matrixes of LO assessment and LO, it is possible to look for a match for each individual cell or to look at the general matrix and look for the best match possible. Complexity rises when it is considered that for one individual LO one might have not only one assessment method but also a combination of methods. On the other hand, one might have a combination of LO that might have a match on one single assessment method or a combination of assessment methods. Both situations occur at course level, when we have several LO that are assessed in a single essay. Also we might have a single LO that will be assessed using a test and a practical case. The model ALOE is prepared to answer these and other questions.

After developing the conceptual model and reaching a final version of ALOE, it was applied to several case studies to test the potential for implementation. For the implementation stage it was necessary to translate the model into practical tools that could be used by the stakeholders. The conceptual model ALOE was used to structure a relational database that include the following components:

a) Reference on assessment: detailed description of the general assessment methods
b) Reference on Engineering education: detailed description of the engineering qualification frameworks
c) Information about the case studies:
d) General contextual information
e) Detailed description of LO
f) Detailed description of assessment and e-assessment

The database of ALOE was complemented with a workflow diagram for the analysis of the case studies in terms of alignment. Two scenarios of implementation were considered: verification of current alignment and improvement of alignment using suggestions for assessment methods. Implementation was tested using eight case-studies from different fields in engineering education. As indicated above, for each case study, the information was collected using documental research and interview with the faculty member responsible for the course. Each intended LO was analyzed in detail and mapped to the LO matrix. The same procedure was done to each assessment method. Each individual exam question, problem, project was analyzed and mapped to the rBloom matrix. To verify alignment, matrixes were compared. The results of the case-studies were discussed with the teachers.

6. Conclusions

Assessment of student learning is a complex field of research. Assessment and learning are deeply contextualized processes and it is not possible to have a solution that fits every case. The model ALOE intends to provide a flexible way to guide teachers and institutions the achievement of a better alignment at course and at program level. ALOE is by no means a closed system. It is possible, and even expected, to add or improve the model in terms of assessment methods and of learning outcomes in engineering education. Other professional qualification frameworks, besides ABET and EUR-ACE, may be added allowing testing for alignment to those specific LO. Also, by including the LO of a program and of the corresponding courses it is possible to test the internal alignment of the full program. This could be useful and relevant for accreditation processes and quality evaluation activities of EE.

In terms of the teacher activities the ALOE model can provide support at the two levels when preparing the course teaching activities and planning. The first level of influence is related with the definition of a file for each LO or competence that students need to acquire. The ALOE model can provide options for assessment tasks that can help the evaluation of the student for that particular LO. That can also be provided to the student allowing a clear perception by the student of the usefulness of each evaluation activity. The second level of support for the teacher is the definition of learning activities that will foster the acquisition of that particular competence. That may be helpful to compare with other similar courses in terms of solutions aiming at similar competences. That can provide useful benchmarking when comparing final and partial grades of the students in different courses and contexts.

ALOE is an organized and structured attempt of providing a model to define an understandable and rational mode of evaluation learning given a desired goal in terms of LO. Content provision has been in the past the main rationale for ensuring proper education and training. The model ALOE is independent of the content but it is related with the outputs of the learning activities. That is difficult but may be the proper approach to progress in terms of quality and of reliability of Engineering Education.

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