Presented at the ENAEE Workshop, Brussels, 22 January 2009.

Progressing Towards Global Standards in Engineering Education

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1. Introduction.

In this paper I will present the main results of a comparison I have made of the standards of the EUR-ACE Framework and the Washington Accord, and some thoughts that arise from this comparison on the possibilities for developing global standards of engineering education. The views expressed here are entirely my responsibility, and should not be assumed to represent those of the Engineering Council UK or of the European Network for Engineering Education (ENAEE).

I am going to consider only the educational phase of qualifying as a professional engineer, and not any subsequent post-graduation phase of training and experience that is integral to qualifying in some national systems. In order to limit my presentation, I have considered here only the Second Cycle standards within the EUR-ACE Framework [1], and similarly only the Washington Accord of the several agreements of the International Engineering Alliance [2].

I have chosen to use the comparison of the standards of the EUR-ACE Framework Second Cycle and of the Washington Accord because they have similar objectives in establishing over-arching frameworks for accrediting agencies. Furthermore, both systems are based on specifying requirements in terms of the outcomes of programmes. In principle I could have chosen to make comparisons with other systems as my starting point, including published national systems of accreditation (eg ABET, Netherlands Technical Universities, etc), but an advantage of over-arching systems is that they avoid any cultural and historic traditions of national systems.

2. General Considerations.

The processes for accrediting programmes of engineering education should contain four basic elements:

- a specification of the content of the programme;
- a specification of the level of the programme;
- an assessment of the resources to deliver the programme;
- a procedure for evaluating and deciding on the above three elements.

We would therefore expect that a framework that is intended to assess the standards and the effectiveness of accreditation agencies would have statements about the expectations in each of these four elements. I am going to address directly only the first two of the above elements, those of content and level, for two reasons. Firstly, the Washington Accord does not specify directly the criteria for programme resources or decision making, although these aspects are fully evaluated when the procedures of the signatories are assessed. Secondly, the omitted elements are not primarily about the standard of the outcomes of engineering programmes, but more about the quality of the organisational arrangements of the university and the accrediting agency respectively. These two elements are important for quality assurance, but not directly germane to comparing engineering standards.

3. Programme Content.

I have used Content here to mean the stated outcomes that the EUR-ACE Framework and the Washington Accord specify should be in the engineering programmes assessed for accreditation. The EURACE Framework identifies Programme Outcomes under six headings which are listed in table 1. Under these headings there are 21 Programme Outcomes for First Cycle degrees, and 19 for Second Cycle degrees. Integrated programmes which progress directly to Second Cycle level are required to satisfy all the First and Second Cycle Programme Outcomes, although it could be that in practice some of the former will be subsumed into some of the latter. The format of the Washington Accord is different. The outcomes are tabled as Graduate Attributes, supplemented by a further table of Range and Contextual Definitions. The headings of the 13 Graduate Attributes are also listed in Table 1, arranged to match, as far as possible, those of the EUR-ACE Framework.

It will be immediately evident from the table that there is a strong similarity between the two lists of headings. The major difference is that the Transferrable Skills heading of the EUR-ACE Framework incorporates several of the separate Washington Accord headings. This classification in terms of headings is more a convenience to assist presentation and interpretation rather than fundamental to accreditation; we need to look in more detail at the requirements underlying the headings.

The results of the comparison that I have carried out of the Content requirements of the two systems are shown in Annex 1. As an example, consider a particular Graduate Attribute from the Washington Accord:

> *Identify, formulate, research literature and solve* complex *engineering problems reaching substantiated conclusions using first principles of mathematics and engineering sciences.*

Table 1. Headings of Outcomes in the EUR-ACE Framework and the Washington Accord.

EUR-ACE Framework	**Washington Accord**
	Academic education
Knowledge and understanding	Knowledge of engineering science
Engineering analysis	Problem analysis
Engineering design	Design/development of solutions
Investigations	Investigation
Engineering practice	Modern tool usage
Transferable skills	Individual and team work
	Communication
	The engineer and society
	Ethics
	Environment and sustainability
	Project management and finance
	Life long learning

The definition of complex is relevant to the discussion of Level which I will consider shortly. We can look for equivalent requirements of student achievement from the Second Cycle Programme Outcomes of the EUR-ACE Framework which require (among others):

The ability to solve problems that are unfamiliar, incompletely defined, and have competing specifications;
The ability to formulate and solve problems in new and emerging areas of their specialisation;
The ability to use their knowledge and understanding to conceptualise engineering models, systems and processes.

There is clearly some similarity of the wording of the two systems, and, although the two requirements are not identical, we can infer some equivalence. The table in Annex 1 shows that it is possible to find for each of the Graduate Attributes of the Washington Accord matching Programme Outcomes from the EUR-ACE Framework. The conclusion that I draw is that the specifications of Content in the two systems are not significantly different. In other words, I have found no fundamental inconsistency between the Content of the Second Cycle of the EUR-ACE Framework and the Washington Accord.

There is a possible criticism of this conclusion. How do I know that I searched hard enough to find differences or inconsistencies between the two systems? A major difficulty in undertaking a more detailed search is that of semantic interpretation. The meanings of words such as design, mathematics, problem solving, etc, intended by the authors of the two systems are almost certainly different, even if only slightly so. Further, whoever uses the standards in developing or in evaluating a programme may also have a different interpretation. This intrinsic feature of interpretation therefore sets a limit to the fineness of differences one can seek to identify by looking at the statements of requirements. A glossary of would help to reduce the variability of interpretation, and would therefore be directly relevant to developing global standards.

4. Glossary.

In comparing the two systems, several questions arose related to the interpretation of the requirements.

- Do the apparent differences between the two sets of requirements arise more from semantics than from principle?
- Does the use of the same words (eg design) give an illusion of agreement that obscures differences of principle?
- Does the structure and syntax of the requirements significantly affect the meaning of individual words?
- Assuming that English is used as the working language, are the criteria expressed so that they are readily interpreted by non-native English speakers?

The development of an agreed glossary of key words will help to reduce the effect of differing interpretations. A comprehensive glossary has been developed [3] within a recent EC supported project, and could provide a basis for framing and interpreting requirements.

I shall assume that the difficulties of interpretation are capable of being resolved to the necessary accuracy, and that therefore in this paper there are no uncertainties of meaning. Except for one particular statement, I have assumed that the words I use have exact meanings.

5. Programme Level.
I have used Level to mean the depth of knowledge and understanding specified in the two systems for a graduate from an accredited programme.

In the EUR-ACE Framework the Programme Outcomes under the headings Engineering Analysis, Engineering Design and Investigations are described as needing to be 'consistent with their [the students'] level of knowledge and understanding'. The level required is specified by one of the Second Cycle Programme Outcomes under the heading Knowledge and Understanding:

> *'a critical awareness of the forefront of their branch'.*

This short statement defines the Level, and is consistent with the Dublin Descriptors which apply throughout the European Higher Education Area. However, although it states that the EUR-ACE standards have some link to the forefront of the subject, it is not immediately evident how to interpret this requirement.

In the Washington Accord the Level of the Graduate Attributes is identified through 'complex' problems, and that quoted previously when discussing Content is typical:

> *Identify, formulate, research literature and solve* complex *engineering problems reaching substantiated conclusions using first principles of mathematics and engineering sciences.*

A complex engineering problem is described in some detail in the Table of Range and Contextual Definitions and includes the following characteristics (among others):

> *'cannot be resolved without in-depth knowledge';*
> *'involve wide-ranging or conflicting technical, engineering and other issues';*
> *'have no obvious solution and require abstract thinking';*
> *'requires in-depth knowledge that allows a fundamentals-based first principles analytical approach'.*

This description of complex problems is comprehensive and detailed but I suggest that it does not specify the Level. In fact the description of complex problems and activities in the Washington Accord is more of a specification of ways of assessing learning outcomes of a programme than for determining its level. An engineering problem could be complex, without being at the leading edge of technical development. To illustrate my argument, I have included in Annex 2 some examples of student projects that I suggest are complex problems within the above description. What is important in these examples is not that they are undertaken by students (sometimes successfully, sometimes not), but that they are complex within the description of the Washington Accord, although they are not at the leading edge (or forefront) of the subject. This implies that the Washington accord does not specify an identifiable Level.

Have I misunderstood or misinterpreted the Washington Accord? Should I have tried to determine the Level from the totality of statements? Perhaps, but even if I have interpreted the Washington Accord incorrectly, I suggest that it is possible to do so because the Level is not clearly specified, and that a more direct statement is needed.

I conclude from the above arguments that it is not possible to compare directly the Level of the two systems, because neither is sufficiently explicit. In the EUR-ACE Framework the Level is simply stated, but requires clarification in order to be useful; in the Washington Accord the Level is not clearly stated and therefore is open to variable interpretation.

6. Where is the Forefront?

If we assume that the EUR-ACE statements of the Second Cycle requirements are acceptable in intention, although the wording could be improved, we need to decide how to apply them in practice. In particular, a number of questions arise when we try to interpret the statement about Level:

a critical awareness of the forefront of their branch.

(a). What criteria should an agency use in order to determine if a programme is at the Forefront? Such criteria are necessary to enable universities to provide the relevant evidence for accreditation, and also to ensure consistency in decision making by the accrediting agency. I suggest that the following activities are capable of providing the necessary evidence, and that agencies will require the university to identify the aspects of the programme claimed to be at the Forefront.

- Project work in the final year of the programme that is directly related to the research programme of the university. The research need not be directly scientific research, but could be a closely associated activity, eg developing instrumentation.
- Project work in the final year on an industrial topic, and which could be carried out in industry depending on the particular teaching arrangements. Such activity would need to be monitored to ensure that it was concerned with using relevant ideas and concepts informed by the forefront in new products, designs, systems, processes, etc.
- A specified number of taught credits in the final year of the programme that are at the Forefront. The credits need not be concentrated into specific modules, but could be distributed throughout the teaching programme in the final year.

(b). Who is to decide if the Forefront requirement has been satisfied? I suggest that the prime responsibility is that of the panel of accreditors who assess the programme; they are experts in that discipline and have detailed information about the programme. Their evaluation of the programme, and their discussion with the course providers is, in part, a debate about the location of the Forefront in that discipline. Of course opinions will differ about its location, but in most accreditation processes the panel of accreditors make a recommendation to a committee that makes the final decision. This two stage process of recommendation and decision is important in assisting consistency of decision making, and also increases participation in the debate on the location of the Forefront.

(c) It will also be necessary for the university to show that its assessment methods are able to demonstrate that the graduates have achieved the specified outputs. It clearly would be unacceptable if the connection to the Forefront was simply a verbal or anecdotal account of recent developments. In fact the list of Graduate Attributes of the Washington Accord in Annex 1 provides a summary of the type of problems and activities that, together with performance indicators, should enable the standard of assessment and achievement to be demonstrated. Of course the form of the connection to the Forefront will reflect the design of the teaching programme and the characteristics of the particular discipline, but it would need to be assessed as relevant and proportionate by the panel of accreditors.

7. Conclusions.
The results of the comparison of the EUR-ACE Framework and the Washington Accord are that:

there is acceptable agreement between the Content of the two systems;

it is not possible to make a definitive statement about the comparative Levels of the two systems because of limitations in the way they have been expressed.

Nevertheless, I have presented suggestions how the idea of Forefront can be used for assessing the Level for accrediting engineering programmes leading to professional qualification. Furthermore the Washington Accord identifies problems and activities that can be applied to assessing the Level. It is possible that the differences between the two systems are more presentational than fundamental, and that there are implicit underlying similarities, which suggests the possibility of reaching agreement on global standards. However there is a major difference between suggesting that an agreement is possible, and its practical development and implementation. Several questions remain.

(a) Is the idea of Forefront the best, or the correct, one to use to identify Level?

(b) Can the idea of Forefront in the EUR-ACE Framework be expressed in a way that can be used efficiently and effectively for the design and assessment of programmes without being prescriptive?

(c) Is it possible to have a consistent interpretation of Forefront in different languages and within different educational and engineering traditions?

(d) Are the arguments presented about the Graduate Attributes of the Washington Accord correct, and can they be used as a basis for programme assessment?

(e) Are the arguments presented here capable of being applied to EUR-ACE First Cycle degrees and other statements of standards?

(f) What type of organisation, or arrangements, would be necessary to monitor accreditation agencies on a global scale to ensure that a consistent interpretation of the standards is being used?

(g) How can we ensure that such an organisation is flexible enough to encourage innovation and development of teaching methods and materials, and does not inhibit the introduction of new ideas?

I am sure that it is possible to find answers to these questions that would enhance the important contribution of engineering and technology to resolving global problems.

References.
[1]. http://www.enaee.eu/images/P1EUR-ACE_Framework_Standards_28.08.08. Accessed 15 January 2009.
[2]. http://www.ieagreements.org/Rules_and_Prcedures_Aug_2007.pdf. Accessed 15 January 2009.
[3]. G.Heitmann. The Glossary of Terms and the Guide of Engineering Schools in Europe. Chapter 7 of Teaching and Research in Europe edited by C Borri and F Maffioli, Firenze University Press, 2007.

Annex 1. Comparison of Washington Accord Graduate Attributes with EUR-ACE Programme Outcomes.

In the table below the column on the left lists the Graduate Attributes of the Washington Accord, and that on the right those EUR-ACE Second Cycle Programme Outcomes which most closely match. It is of course possible to make the comparison in the opposite direction, that is to match the Washington Accord requirements to those of EUR-ACE.

Washington Accord Graduate Attribute	EUR-ACE Second Cycle Programme Outcomes
Academic Education. Completion of an accredited program of study typified by four years or more of post-secondary study.	
Knowledge of Engineering Sciences. Apply knowledge of mathematics, science, engineering fundamentals and an engineering specialization to the conceptualization of engineering models.	an in-depth knowledge and understanding of the principles of their branch of engineering; a critical awareness of the forefront of their branch; the ability to use their knowledge and understanding to conceptualise engineering models, systems and processes.
Problem Analysis. Identify, formulate, research literature and solve *complex* engineering problems reaching substantiated conclusions using first principles of mathematics and engineering sciences.	the ability to solve problems that are unfamiliar, incompletely defined, and have competing specifications; the ability to formulate and solve problems in new and emerging areas of their specialisation; the ability to use their knowledge and understanding to conceptualise engineering models, systems and processes.
Design/development of solutions. Design solutions for *complex* engineering problems and *design* systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations.	the ability to solve problems that are unfamiliar, incompletely defined, and have competing specifications; an ability to use their engineering knowledge and understanding to design solutions to unfamiliar problems, possibly involving other disciplines; an ability to use creativity to develop new and original ideas and methods.
Investigations. Conduct investigations of *complex* problems including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions.	the ability to identify, locate and obtain required data; the ability to design and conduct analytic, modelling and experimental investigations; the ability to critically evaluate data and draw conclusions.

Modern Tool Usage. Create, select and apply appropriate techniques, resources, and modern engineering tools, including prediction and modelling, to *complex* engineering activities, with an understanding of the limitations.	the ability to use their knowledge and understanding to conceptualise engineering models, systems and processes; a comprehensive understanding of applicable techniques and methods, and of their limitations.
Individual and Teamwork. Function effectively as an individual, and as a member or leader in diverse teams and in multi-disciplinary settings.	function effectively as leader of a team that may be composed of different disciplines and levels.
Communication. Communicate effectively on *complex* engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.	work and communicate effectively in national and international contexts.
The Engineer and Society. Demonstrate understanding of the societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to engineering practice.	Fulfil all the Transferable Skill requirements of a First Cycle graduate at the more demanding level of Second Cycle: function effectively as an individual and as a member of a team; use diverse methods to communicate effectively with the engineering community and with society at large; demonstrate awareness of the health, safety and legal issues and responsibilities of engineering practice, the impact of engineering solutions in a societal and environmental context, and commit to professional ethics, responsibilities and norms of engineering practice; Demonstrate an awareness of project management and business practices, such as risk and change management, and understand their limitations; Recognise the need for, and have the ability to engage in, independent life long learning.
Ethics. Understand and commit to professional ethics and responsibilities and norms of engineering practice.	
Environment and Sustainability. Understand the impact of engineering solutions in a societal context and demonstrate knowledge of and need for sustainable development.	
Project Management and Finance. Demonstrate a knowledge and understanding of management and business practices, such as risk and change management, and understand their limitations.	
Life long learning. Recognize the need for, and have the ability to engage in independent and life-long learning.	

Annex 2. What are Complex Problems?

In the Washington Accord, complex problems are described as having some or all of the following characteristics:

- Involve wide-ranging or conflicting technical, engineering and other issues;
- Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models;
- Requires in-depth knowledge that allows a fundamentals-based first principles analytical approach;
- Involve infrequently encountered issues;
- Are outside problems encountered by standards and codes of practice for professional engineering;
- Involve diverse groups of stakeholders with widely varying needs;
- Have significant consequences in a range of contexts;
- Are high-level problems possibly including many component parts or sub-problems.

The four examples of actual problems described very briefly below have at least some of the above characteristics, and therefore could be categorised as complex. But their solutions clearly do not require detailed knowledge and understanding at the leading edge of new technology. I therefore suggest that the level of a degree programme cannot be determined without further information about the level of the complex problem.

In fact these problems are examples taken from a short project scheme for students in the second year of a degree programme, that the Department of Electronic and Electrical Engineering at the University of Sheffield, UK has run for many years. Teams of between four and six students spend a week working on a problem for an external organisation, and those listed below are typical. The students attempt to find possible solutions, sometimes successfully sometimes not, and present a verbal and written report.

Electrostatic Painting. Electrostatic painting is widely used as an efficient method of painting in many industries. However it is often necessary to protect certain areas, such as bolt threads or earthing tags. Is there a better method than the one presently used? Considerations involve method and materials, effectiveness and reliability, cost.

Display Lighting. A museum has a number of displays that need to be illuminated both for access and for use by visitors. Are there cost-effective ways of reducing the illumination when the displays are not being used? Considerations include type of lighting and control methods, people detection, safety.

Induction Heating. Induction heating is widely used method of electrical non-contact heating. For high powers it is necessary to cool some of the electrical components in the electrical circuits, and water cooling is quick and cost-effective. However water leakage and condensation can cause serious problems; can they be detected and prevented?

People Counting. A science centre has a large number of displays which need to be arranged to optimise throughput. How can data be acquired about the number, type (adult, child, group, etc) and dwell time of people at each display?