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A strategy for the development of lifelong learning and personal skills throughout an undergraduate engineering programme

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***Abstract*—For many years engineering programmes have placed a stronger emphasis on the development of technical knowledge, understanding and skills at the expense of personal skills such as initiative, creativity, communication, teamwork and lifelong self-directed learning. Recent changes in accreditation criteria call for greater competences in these skills to be achieved in the undergraduate programme. An argument is presented that this requires a change from the traditional approach to engineering education to a group-based project driven one as this is compatible with concurrent development of both technical and non-technical learning outcomes. Just as a clear path of progression exists from the fundamentals of science in stage one to the advanced engineering content in the final year so too should personal skills be developed in a progressive structured way. This paper presents a strategy that is currently being developed and implemented in the School of Electrical Engineering Systems in the Dublin Institute of Technology in a four year Bachelor of Engineering programme. In the group-based project-driven approach students practice communication and team work skills not in isolation to but integrated with the programme's technical content. The early stages of the programme focus on strongly developing the group learning process and introducing students to a reflective practice so they can observe and improve performance. Tutor observation fades in later years as students become more adept at managing group work and self-directed learning. This strategy is designed to progressively change a dependent freshman student into an independent graduate who is prepared for the challenges ahead.**

Keywords-accreditation criteria, group based learning, PBL, self-directed lifelong learning, reflective practice, key skills, personal competences

I. INTRODUCTION – A CALL FOR CHANGE

Recent changes to the accreditation criteria for engineering programmes in Ireland and elsewhere are a response to the modern phenomenon of globalization. Companies are multi-national, highly mobile, operate in a very competitive environment and must be innovative and efficient to survive. Human capital is very important. The economic landscape is very different to what it was a generation ago, especially so in the science and technology area that many of our graduates join. The engineering profession has changed in such a way that it is no longer sufficient to have a good grasp of the discipline content. Employers need graduates who have more to offer, are innovative, creative, can self start, work successfully in a team and independently update their technical knowledge. Graduates themselves take a very dynamic career path; they may join a discipline they weren't prepared for and are internationally mobile. Engineering education also needs to change how it operates so it can produce graduates that are attractive to employers and attract more students to engineering programmes.

Creativity, initiative and the ability to independently learn are always needed as engineers are continually presented with problems that were not mentioned in their undergraduate studies and commonly find a career outside the discipline they studied. A young engineer may find him/herself working on a project to halt the tilt of the leaning tower of Pisa, replace a chemical synthesis with a bioprocess, move energy production to renewable sources and inform changes in lifestyle, write an application for an iPhone or be faced with countless other challenges that were not on the syllabus. The engineers who will succeed in this environment are those who not only have a strong grasp of engineering content but have also developed competences in team work, open ended problem solving and self-directed lifelong learning and have had the chance to awaken their creativity and practice their initiative.

The call for key skills development comes from other sources in addition to the professional bodies and national qualification authorities. In fact, the need for creativity and critical thinking is not contained in the criteria shown in Table 1 below. A recent government publication in Ireland calls on third level education to foster creativity and innovation [1]:

"The capacity of being able to work effectively with others from across a wide range of disciplines is a feature of the most creative and productive individuals in an enterprise context. In practice, in a learning environment therefore, this should involve engagement in collaborative cross-disciplinary projects as much as possible" [1, p2]

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This is driven by the concern for national competitiveness and job creation. The move to a knowledge economy is a common theme in many countries. Creative solutions to the symptoms and causes of global warming will also be needed and not just at a technical level. There is widespread difficulty in comprehending this problem and understanding that levels of greenhouse gases will not be reduced even if we cut emissions as illustrated in a study with third level students [2]. Forthcoming graduates will have to work hard to communicate and engage with society in general to resolve these issues.

These changes are increasingly reflected in the accreditation criteria of professional bodies who increasingly demand a blend of technical and non-technical skills and attributes. The development of these skills, however, is not complimentary with the traditional method of engineering education that has prevailed for a number of generations. In many programmes these transferable skills are viewed as additional to programme content and often addressed in independent modules far removed from the technical knowledge and skills. However, a change in the output without changing the input requires a modification of the process. We argue that traditional engineering programmes were designed to teach a student that no longer exists and to produce an engineer that is no longer needed.

Significant change can happen by moving some modules in the programme to a group-based project-driven approach to learning. This approach is well established and researched, is based on a widely accepted learning paradigm, and is highly compatible with the concurrent development of technical and non-technical learning objectives.

The School of Electrical Engineering Systems in the Dublin Institute of Technology (DIT) covers the entire spectrum of adult education in our discipline from electrical apprenticeship education through to post-doctoral researchers. The school offers a four year Bachelor of Engineering in Electrical and Control Engineering with approximately 30 students in each year. In an effort to respond to the change in accreditation criteria and motivated by a desire to move to a student-centred approach to learning we are growing the number of group-based learning modules in the programme. We believe this should be done in a way that allows each student to progressively develop her/his key skills during each year of the programme. This is the common approach to the development of technical knowledge in any programme: the basics are covered first before progressing to intermediate level with advanced content delivered in the final stages. The same progressive approach should apply to development of non-technical skills so that sufficient time and attention can be given to each. This is much more likely to ensure a high level of attainment or competence is reached in each one and that the accreditation criteria are satisfied.

In the last number of years many programmes have been accredited by the professional body, Engineers Ireland, based on the new criteria despite relatively minor changes in their curricula. Some confusion exists as to what extent the key skills should be developed and how this should be facilitated in a programme. Is one group-based module in the entire programme really sufficient to satisfy half the accreditation criteria? Or should a significant change be made to the curriculum to allow a more complete delivery of the non-technical learning outcomes? In this paper we propose a framework for the progressive development of key skills throughout an undergraduate programme that will help guide those who wish to change curriculum to strongly deliver on all of the accreditation criteria

II. Accreditation Criteria

The accreditation criteria for an honours bachelor degree engineering programme in Ireland are very similar to elsewhere in the world. A comparison of criteria from Engineers Ireland and the Accreditation Board for Engineering and Technology (ABET) in the US for example shows close agreement on what skills and attributes an engineer should have. These criteria demand the development of a large amount of discipline specific knowledge and a wide variety of non technical skills during the engineering programme. A summary can be seen in Table 1 which also shows how compatible the two learning and teaching methods that are compared in this paper are with significant development of each criterion. (The degree of compatibility is not shown in one case where attainment is based more on content than the learning and teaching approach).

Engineers Ireland justifies the need for these skills but does not provide any guidance or direction on how to achieve them. The challenge for engineering educators is to design a curriculum that delivers strongly on all of the accreditation criteria, enhances learning and is a positive, challenging and rewarding experience for the students and staff. As can be seen in Table 1, we believe the group-based project driven approach is much more suited to delivering this set of accreditation criteria and provides direction for a change in engineering education.

III. The Traditional Approach to Engineering Education

The traditional approach to engineering education has tended to be teacher-centred with modules delivered by lecture and recipe based laboratory practicals. There are a number of advantages to this approach: it is simple to implement, is easily understood by staff and students, it does result in learning, does not require excessive contact time and complex material can be delivered in one semester. Although it can be adapted to increase the amount of interaction with and engagement of students in the learning process, it is largely based on a behaviourist view of learning where all students are assumed to behave the same, learn at the same pace and in the same way. Assessment is normally limited to written examination and covers a very narrow set of learning outcomes. Although this approach is often associated with surface learning, it can be very effective and efficient for the development of understanding if the students have already developed the ability to assimilate and synthesise knowledge and are motivated to do so. However, many students do not have adequate skills to be able to simply 'absorb' knowledge and develop an understanding through independent learning. In addition, this approach does not foster the development of the key skills, in

TABLE I. ACCREDITATION CRITERIA FROM ABET IN THE US AND ENGINEERS IRELAND [3, 4]

ABET	Engineers Ireland	Compatability	
		Trad-itional	Group based
ability to apply knowledge of mathematics, science, and engineering ability to design and conduct experiments ability to analyze and interpret data	The ability to derive and apply solutions from a knowledge of sciences, engineering sciences, technology and mathematics; to design and conduct experiments and to analyse and interpret data	High	High
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	The ability to design a system, component or process to meet specified needs	Medium	High
ability to function on multidisciplinary teams	The ability to work effectively as an individual, in teams and in multi-disciplinary settings	Low	High
ability to identify, formulate, and solve engineering problems	The ability to identify, formulate, analyse and solve engineering problems;	High	High
understanding of professional and ethical responsibility	An understanding of the need for high ethical standards in the practice of engineering, including the responsibilities of the engineering profession towards people and the environment;	Low	High
ability to communicate effectively	The ability to communicate effectively with the engineering community and with society at large.	Low	High
broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context		Low	High
recognition of the need for, and an ability to engage in life-long learning	the capacity to undertake lifelong learning;	Low	High
knowledge of contemporary issues			
ability to use the techniques, skills, and modern engineering tools necessary for engineering practice		High	High

particular creativity, critical thinking, communication and interpersonal skills, nor does not allow for the level of deep learning that can be achieved through interaction and discussion.

As explained by Biggs and Tang [5], where the majority of students are highly interested in and committed to the programme, have an effective approach to learning and are already academic in nature, the method of teaching is less important. These students will succeed in any learning environment and have traditionally succeeded in the traditional lecture based approach to learning. However, as they point out, many students nowadays do not enter college with these qualities, appear to be less interested, less motivated and are less likely to succeed in a lecture based approach in which they are the passive recipients of information. Active learning methods such as a group-based project-driven approach, on the other hand, allow the apparently unmotivated students to reach higher levels of cognition such as reflection, application and comprehension [5, 6].

The traditional approach is not averse to the development of personal skills, it is merely that their development is not compatible with this approach to education. Personal skills are considered to be extra, additional elements and it is expected they will be developed through extra-curricular activities and transferred to engineering practice prior to graduation or else this must happen when the graduate joins the workforce after formal education is complete. Where they are addressed it is often within a stand-alone module, separated from the technical aspects of the discipline and out of context. There is often little or no consideration for how these skills can be progressively developed. For example, what are the first steps in developing teamwork, critical thinking or reflection skills; how can the programme be structured so that these skills are gradually developed?

It is not sufficient to aspire to the achievement of these skills without facilitating their development. They are required by the professional bodies and, in turn, the employers. The individual student can only benefit by developing them; it is these skills and attributes that are probed in job interviews and admired in the profession. They do not appear by magic; no matter what context they are developed in, the process takes time and effort. As engineering educators we should put in place a mechanism to develop these skills and develop them in a logical, coherent and structured way. Just like technical knowledge is progressed from the basics in year one to advanced content in the final year, so too should the key skills be progressively developed through a compatible method of learning.

IV. The Group-Based Project Driven Approach

To deliver on the two areas of discipline knowledge and non-technical skills that appear equally in the accreditation criteria we need a learning and teaching approach that integrates both. A method of learning technical knowledge that is compatible with the concurrent development of non-technical skills is required. A solution exists in group-based project-driven learning where the students learn to work both independently and in groups on complex open ended problems that expose them to discipline specific content. The development of non-technical skills is a core element in this approach to learning. This student-centred approach is based on the constructivist belief of learning in which students are encouraged and required to develop or construct their own individual understanding of programme content.

Students are placed in groups of 4 (small group) to 8 (large group) members and, without prior instruction, are presented with a carefully crafted problem that is based on the module content, is contextualized in a meaningful way and is complementary with the students' prior knowledge. The group then begins an iterative cycle of (i) discussing the problem in the group to develop a list of tasks or learning goals, (ii) working independently on one or more of the tasks before (iii) a second meeting with the group to explain in their own words the work done on the task. This allows the group to resolve issues and move on to develop the next set of tasks as the cycle starts again. The first part can be considered as the brainstorming phase, the second is the self-directed learning phase and the third is the reporting phase. The group process is facilitated by a tutor during the first and third phases. This is a very enjoyable experience for students tutors and especially so for engineers who enjoy the problem solving process. The tutor must nurture the learning process and endeavour to keep this centre stage. The products from the group (reports, presentations, designs, prototypes, etc.) will be good if the group process is working well. The tutor must ensure the group retains ownership of the problem; the Socratic dialogue is used in preference to answering questions directly [7] although care must be taken to use this method correctly to prevent the conversation from becoming 'guess what's on the teacher's mind' [8].

There are a number of different variations on this general approach. A popular model for implementing this approach is problem-based learning (PBL) in which students are divided into groups and learn through actively engaging with meaningful problems [9, 10]. It is common in engineering for students to be asked to build some artefact and in this case the problem becomes a project. Hence, other terms such as project-based learning, inquiry learning and project-oriented problem-based learning exist. The important features of these different implementations are that they are group-based and the learning is problem or project driven. They afford the development of key skills and have been shown to be more effective in facilitating meaningful learning, fostering critical thinking skills and self-directed learning [11]. A study of employers reported by Moesby [12] compared the attainment of technical and non-technical skills amongst two groups of graduate engineers, one from a traditional engineering programme and one from a group-based project-driven programme. The attainment of technical skills was equal in both but those who experienced group learning scored significantly higher in people management, creativity, innovation and other key skills.

V. Traditional and Group-Based Project Driven Approaches Compared

In figure 1 below we show a hypothetical graph that compares the attainment of technical and non-technical skills in a traditional programme and one modified to include a constant delivery of group-based project driven modules. Where sustained attention is not given to the development of non-technical skills in a traditional programme their general attainment in the body of students can be considered to be low while the attainment of technical skills will be high. A large project may occur in the final semester of the final year in which case the student is suddenly exposed to the need for non-technical skills and will start to develop them at that point. Often, the success of the final year project depends on rapid development of self-directed learning and creativity and when this does not happen the student receives a low mark. If the final year project is done on an individual basis then the need for group skills does not arise at this point and they remain undeveloped.

On the other hand, in the programme that contains at least one group-based project-driven module in every semester there is a steady increase in both technical knowledge and key skills. This assumes a coordinated development of the key skills as suggested in this paper. A coordinated delivery of non-technical knowledge and skills is assumed to exist in both types of engineering programme, traditional and group-based.

VI. Progressive Development of Personal Skills

Like any method of teaching, successful implementation of group-based learning requires good planning based on careful thought and best practice. The level of group work skills and the degree of independence of the students in self-directed

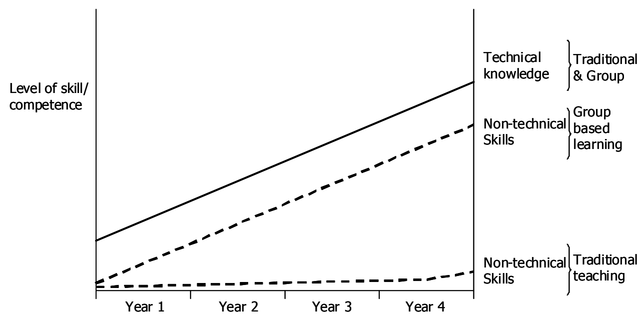

Figure 1. A comparison of the development of technical knowledge and non-technical skills in traditional and group-based project driven programmes

learning have a major influence on this learning and teaching method. It should not be assumed that students have these skills to any significant extent at the start of a programme yet an effective learning group needs to be established as soon as possible. A more detailed structure for managing the problem solving process than the one outlined in section IV above will be needed at this stage. Such significant support and guidance are needed at the start but can be faded over time as the students progressively develop the skills needed to learn in a student-centred environment and fine tune their own approach to learning.

The role of the tutor changes over time from modeling the correct behaviour in a learning group to coaching students to copy this behaviour and eventually fading from the group. The tutor moves over time from the central focus of the students to become an observer of the group. The students become more and more self-directed in their individual approach to learning and in managing their groups. They are more likely to succeed at this if they develop a reflective practice. They must learn to observe, analyse and evaluate their performances in the group and on their own and also modify their approach to improve performance. This is a great challenge for any student, requires time, support and progressive development.

VII. THE FRAMEWORK

The professional bodies have presented a list of skills and attributes every graduate engineer should possess. We have identified a method of learning and teaching that can respond to these requirements. In this section we outline a framework that we are developing to deliver on each of the non-technical skills in a coordinated manner.

A. Criteria of the framework

Let us start by identifying the criteria that this framework should have:

- At least one group-based project-driven module in each semester,
- The learning process is assessed and developed through regular focused feedback on group collaboration skills before attention is turned to the product of learning; the emphasis on the process is reduced as the programme progresses,
- Problems or projects become more and more complex with time in a coherent and structured approach,
- Each module progressively develops a range of skills (group, communication, critical thinking, creativity, project management, reflection and so on),
- Each module integrates more and more social and ethical issues,
- Students progressively move towards professional practice,
- The learning outcomes reflecting the increasing degree of complexity and the increased competences in the range of skills,
- A continual change from the tutor focusing on the individual to the individual focusing on him/herself,
- The level of tutor feedback and interaction reducing as the programme progresses,
- The source of direction moves from the tutor to the student over time and
- A reflective practice is constantly developed

To date we have focused on the two most important areas that must be developed for this method of learning to work effectively, namely group collaboration skills and reflection.

B. The group learning process and distinction from product

Student-centred learning is only possible if each student has a clear understanding of what is expected of them in this environment. This requires a good understanding of what learning is and how it happens. From the beginning each student should become aware that learning is facilitated through guidance, experience, discussion, making mistakes, exploration, reflection and in context. Each member of the group must operate effectively for the group learning process to be positive and productive. If members do not have a clear understanding of what does and does not work from a learning point of view then problems will arise. To develop this understanding an emphasis must be placed on the learning process at the beginning of the programme. An induction workshop on this student-centred approach to learning should be provided in the very first week and quickly followed by the experience of a group-based module. The induction workshop should probe students' beliefs about what skills and attributes an engineer is expected to have, what the professional body expects, what learning is, how learning happens and how it is best facilitated.

A strong emphasis on the learning process should continue throughout the first year. "Lack of interaction is the most common problem in small group teaching" [8, p62]. Group collaboration skills include the ability to talk and discuss, offer an idea, defend one's position, question others, debate and negotiate, criticize another in a positive way, accept and delegate tasks, summarise the group's position, teach others, ensure own and other's understanding is correct, look for mistakes, be open, explain new understanding and provide evidence and help to analyse and reconcile conflicts and differences. This is a considerable list of attributes and requires a significant period of formative evaluation and feedback to the student. Providing guidance on group collaboration skills avoids the need for students to figure out this complex process for themselves and allows cognitive activity to be more focused on the problem at hand [13].

The role of the tutor in the first year is primarily to get the students to work as learning groups by offering practical advice, getting them to do some exercises to develop group skills, encouraging them to provide feedback on the interactions in the group, how they are handling discussions, resolving conflict, making decisions, delegating tasks and managing self-direction. Significant time should be given to these activities while working on technical, engineering projects. Assessment and feedback should focus on the process and not the product, good and all as that may be, at this point.

Low student-teacher ratios are required at this stage to properly facilitate this development but teaching time will be faded over the later years and a pay back in time realised. In the beginning, the students all look to the tutor for answers to all questions, no matter how simple. By the end of the first year this approach should be modified and the students should only use the tutor when absolutely needed having already attempted to answer the question either themselves or through discussion with their group.

The focus on the learning process can be relaxed in the second year, further relaxed in the third year and minimized in the final year. As teacher observation fades it should be replaced by analytical and evaluative reflective journals that identify individual contribution and effort which can be assessed and used to monitor individual performance. Time becomes increasingly available from the second year onwards for the tutor to focus on other personal skills such as creativity and critical thinking. After the first year, problems or projects should be specifically designed to draw out these competences. The community should be considered as a rich source of projects that have a real end-user or customer, often require significant creativity and critical thinking and provide the student with the opportunity to communicate with people outside their profession and develop a social awareness.

C. Reflection and self-directed lifelong learning

The key to a lifelong habit of self-directed learning is the development of a reflective practice. Schön [14] used the term ‘reflective practitioner’ to explain how professionals are most effective when they use reflection to cope with new challenges and situations. Each engineering student should start her/his journey to becoming a reflective practitioner when they join the programme so that by the time they graduate they have already demonstrated a strong degree of independence and responsibility in learning. A student can reflect on her/his performance in a particular context such as a group meeting, how an individual task was managed or a presentation delivery. S/he can also reflect on learning itself and how s/he is learning with a view to improving her/his understanding of learning and learning style.

There are two major parts to the reflective process. "Reflection often involves me in thinking how I did something - which is analytical. It can also involve me in thinking about how well I have done something - which is evaluative" [15, p17]. During the first year the student should learn how to honestly and accurately observe and describe her/his performance. S/he should also learn how to evaluate and criticize performance by identifying what went well, what didn’t, the good and bad points. Planning for future performance should follow by describing what will be done differently next time and how behaviour will be modified. There is much to reflect on in group learning. Many skills need to be developed for interaction to happen and the group to become effective as described above. Each student will need to modify behaviour in some way which means each individual must first learn to observe, analyse and evaluate performance, i.e. start becoming a reflective practitioner.

The individual approach to learning should be improved through reflection. As explained by Biggs and Tang [5], less and less students are entering university having already developed effective approaches to learning. In the first year the student should become aware of what her/his preferred learning style is and how this relates to an effective learning cycle such as that proposed by Kolb [16], so behaviour can be modified and improvements made. Group-based learning is compatible with development of self-directed learning but significant support and guidance should be provided at the start of the programme and faded over time as the source of direction in learning is gradually transferred from the tutor to the student [17].

As with group collaboration skills, students should receive a workshop on critical reflection in which a variety of reflective models, for example Gibb’s reflective cycle [18], are explained and different reflective methods are introduced and practiced. Students should then begin to do some reflective writing in the first semester which should be guided to help improve the group learning process, including the self-directed phase. Regular feedback from the tutor should be provided and this should point to the need for greater analysis, evaluation and planning over time. In other words, students should progress from observing and describing what happened, to analyzing the performance, making some judgements and planning for future improved performance.

Self-assessment should only follow once a foundation has been laid in reflective practice and therefore should be introduced in the second year. At this stage, self-assessment should be based on criteria provided by the tutor and feedback from the tutor’s observation and evaluation of her/his performance will be needed to reconcile the difference between tutor and self-assessment

As these differences are reconciled in the subsequent years in the majority of students self-assessment can be based on criteria developed by the student. These criteria should be based on the project the student is working on and should include attainment of technical knowledge and demonstration of personal competences.

Critical reflection on learning and performance will help to satisfy the accreditation criteria that relates to self-directed lifelong learning. At the end of the undergraduate programme the student should have the following competence in self-directed learning:

- Observe and describe her/his performance in any context
- Analyse performance and identify gaps in understanding and skills
- Plan a learning task to resolve these issues, distinguish ways of addressing the gap and develop a strategy to locate information
- Identify, locate and access suitable resources in a timely manner

- Critically appraise resources, reject those that are not suitable and continue to find useful ones
- Communicate the new knowledge or demonstrate the new skill
- Reflect on the learning task to both analyse and evaluate it, informed by own learning style and accepted learning cycles
- Develop the habit of repeatedly carrying out this approach

(Adapted from [17, 19, 20])

VIII. Conclusions

Engineering education needs to change in order to improve the quality of learning, the learning experience and pay more attention to the non-technical skills that are increasingly required by the professional bodies and other agencies and are needed by graduates. This can be achieved by moving to a group-based project driven learning and teaching method. The non-technical skills should be addressed in a structured way that allows their progressive development throughout the programme. An emphasis should be placed in the early years in developing effective group collaboration skills, a good understanding of the learning process and critical reflection. This can be relaxed in subsequent years as students become more self-directed and groups more autonomous. The remaining personal skills can then be addressed by the use of appropriate problems and projects with serious consideration given to the use of community projects to develop creativity, initiative, social awareness and communication with society.

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