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Equipping Future Engineers with Competences to respond to the SDGs: Insights and Implications for Engineering Education

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***Abstract*—The importance of developing undergraduate students' appreciation and understanding of the Sustainable Development Goals (SDGs) is recognised in many UK and Irish universities via inter alia, their internal quality assurance processes and their links with the professional bodies and learned societies which accredit their courses. Few disciplines are as well-placed and relevant in the solution of complex global problems as epitomised in the 17 SDGs, the so-called 'wicked' problems, as engineering.**

Work has been carried out in identifying the skills that engineers of the future will need if they are to contribute solutions as fully as is required. However there remains a knowledge gap in how best these skills can be translated to competences; and indeed which competences are prioritised among employers. The undergraduate engineering curriculum is already packed with traditional engineering subjects such as maths, science, engineering analysis, and so on. Therefore, the challenge for engineering educators is how the already-packed curricula can be revised or re-engineered so that the engineering graduates of the future will be equipped with the relevant knowledge and practical know-how to contribute positively and sustainably in industry.

This paper describes the results of a professional skills survey, developed using previous European-level research, and administered among employers, academics and students on the island of Ireland. The broader context is somewhat unique: two jurisdictions (one British, one Irish) on a shared island. Analysis highlights interesting similarities and differences in perspectives among survey respondents and helps elucidate the teaching priorities of the wider engineering education community.

***Keywords*—engineering education, competences, SDGs, professional skills**

I. Introduction and Literature Review

The UN 2030 Agenda, the 17 Sustainable Development Goals (SDGs) and the climate emergency present both challenges and opportunities, and bring a sharp focus on the work of the engineering education community. Technical competence alone for graduate engineers is insufficient. Hence there is a renewed emphasis on undergraduate engineering students being equipped with the appropriate professional skill-set that they will need to be able to tackle the critical issues that society needs and demands.

The professional skills required by engineers have been the subject of much research: generally, at national or international level (Passow and Passow [1], Male et al. [2], Kovesi and Csizmadia [3], Colman and Willmott [4]). More specifically, influential work conducted by (Wiek et al. [5], de Haan [6], Rieckmann [7]) considered the skills required for sustainable development.

A recent European study (Beagon et al. [8]) narrowed the focus further to competence requirements for engineers to support the achievement of SDGs. It presented 53 competences in six main categories: though it reported a lack of agreement on which should be prioritised.

This paper aims to contextualise the 53 competences identified by Beagon et al to a smaller scale (national, regional). It explores and compares stakeholder perspectives on the specific professional skills required for engineers on the island of Ireland in the context of achieving the SDGs.

Acknowledging that a list of 53 competences could be overwhelming for educators, this research seeks to identify contextually relevant priorities, and should prove useful in informing educational initiatives in individual universities within a geographical region.

II. Method

A. Approach

This research was conducted as part of a Higher Education Authority (HEA) funded project entitled PROFESS 12. One aim of the project was to design and test an innovative Summer School to help students develop skills to solve SDG 12. A survey was circulated as a pre-cursor to the design of the Summer School to ascertain appropriate teaching activities according to the localised and prioritised skill set requirements of survey respondents on the island of Ireland.

A professional skills survey, developed using Microsoft Forms, was based on previous research [8] which identified (at European level) the skills that engineers need to meet the SDGs. Ethical approval for the survey was granted by the Research Ethics and Integrity Committee in TU Dublin (REIC-21-74). The survey (piloted pre-launch (November 2022)) requested information on respondent profile capturing attributes such as category (academic / employer (including sector, size) / student (including year)) and demography (gender, age, region). The first question seeking stakeholder perceptions explored awareness of the SDGs. Other questions sought ratings on importance, preparedness of engineering students and graduates and then priorities for teaching with reference to the 53 competences identified in six competence sets [8]. Finally, an open text response was provided for additional feedback (if any).

Invitations to participate in the survey were issued (primarily via email) to:

- **students** in TU Dublin and Ulster University;
- **academics** in the research team's personal networks (wider than TU Dublin and UU); and
- **engineering employers** in the research team's personal networks and through professional engineering institutions (such as Engineers Ireland, Institution of Structural Engineers).

B. Limitations

This paper presents findings from an exploratory scoping survey which provides a snapshot of perspectives on priorities for skills to address SDG challenges for future engineers. Key limitations associated with the findings relate to research design and questionnaire design:

- (research design) the number of questions was restricted to minimise respondent burden so descriptive information about respondents is minimal;
- (research design) the survey invitation was shared with a limited population (in terms of size and characteristics) of potential respondents (due to practical and resource constraints); without such constraints, a larger, potentially more diverse population could be surveyed;
- (questionnaire design) standard definitions for employer categories (SME, National, Multi-national) were not included. Respondents self-selected a category and may have applied different interpretations to the categories,
- (questionnaire design) the questionnaire did not seek respondent job title. Whilst it targeted technical engineering staff, other staff (e.g. HR colleagues), who may not have such close working knowledge of graduate skills, may have completed it.

The research design limitations in particular restrict our ability to comment on representativeness of findings. This in turn limits the extent to which findings may be generalised.

III. Results and Discussion

This paper describes findings on awareness of SDGs and importance of the competences only. The particular focus of this paper is to analyse survey responses by category of respondent (academic, employer, student) to examine which competences are rated most important by category. Key findings are presented, with initial consideration given to the profile of respondents, followed by awareness of SDGs and then importance of competences for engineers.

A. Profile of Respondents

As shown in Table I, of 235 survey respondents, just over one third were from Northern Ireland (NI) (n=88), with most from Ireland (n=147). A small number of responses (n=7) from elsewhere were excluded from the analysis.

Students provided most responses (over half, 54.9%); academics were the next most common respondent type, accounting for almost one quarter (23.0%) of responses. Employers (mostly multi-nationals and SMEs (8.9% respectively) and nationals (4.3%)) provided the remainder.

TABLE I
Profile of Respondents by Category and Jurisdiction

Category	Northern Ireland		Ireland		All	
	N	%	n	%	n	%
Academic	17	7.2%	37	15.7	54	23.0%
Employer – Multinational	7	3.0%	14	6.0%	21	8.9%
Employer – National	1	0.4%	9	3.8%	10	4.3%
Employer – SME	6	2.6%	15	6.4%	21	8.9%
Student	57	24.3%	72	30.6%	129	54.9%
Total	88	37.4%	147	62.6%	235	100.0%

B. Awareness of Sustainable Development Goals (SDGs)

TABLE II
Awareness of SDGs by Category and Jurisdiction

Category	Northern Ireland	Ireland	All
Academic	3.9	4.2	4.1
Employer – Multinational	2.7	3.6	3.3
Employer – National	3.0	3.3	3.3
Employer – SME	2.3	2.9	2.8
Student	2.4	3.2	2.8
Total	2.7	3.5	3.2

Overall **awareness of the SDGs** measured on a 5-point Likert scale (5-*Extremely Aware* to 1-*Not at All Aware*) was 3.2 (*somewhat* to *moderately aware)*. However, awareness was not consistent within categories (see Table II): unsurprisingly it was highest (4.1) amongst academics. Awareness in all employer categories was markedly lower: an average of 3.3 for multi-nationals and nationals respectively. SMEs and students had lowest levels of awareness (2.8 each).

The level of awareness amongst respondents in Ireland is 3.5 (between *somewhat* and *moderately aware)*, which is considerably higher than awareness in NI, 2.7 (closer to *somewhat aware*). This is echoed across all categories of respondent with higher awareness perceived in Ireland. Given the relatively small numbers of respondents in each of the employer categories in particular (see Table I), any more granular comparisons should be treated with caution. The implication of this finding indicates that there is scope to raise awareness further, particularly in NI and amongst employers and students. This could be immediately addressed in the design of engineering education programmes. There may also be scope to identify (and learn from) effective initiatives to raise awareness (perhaps led by government, professional engineering institutions) from other jurisdictions (including Ireland) where employer awareness is higher.

C. Importance of Competences: Most Important Individual competences

Respondents rated importance on a 5-point Likert scale (5-*very important* to 1-*not important*) for 53 competences in six sets. Specifically, they were invited to indicate how important each competence is for engineers of the future to help solve the SDGs. For reference, the competences included in each set are [8]:

1. **Fundamental Technical Skills** (Mathematics Skills, Digital Skills, Economic Skills, Research Skills, Technical Skills);
2. **Application Skills** (Multidisciplinary Skills, Problem Solving, Design Skills, Interpretation Skills, Conceptual understanding, Resources optimisation, Innovation, Entrepreneurship, Decision Making Skills, Learning to Learn, Project Management, Organisation Skills, Problematisation (to consider or treat as a problem));
3. **Outward Facing–People Orientated Skills** (Intercultural Skills, Collaboration, Leadership, Conflict Management, Negotiation, Communication, Respecting Diversity, Teamwork);
4. **Inward Facing–Ways of Thinking** (Critical Thinking, Life Cycle Thinking, Holistic Thinking, Systems

Thinking, Creativity, Analytical Thinking, Stress Management, Time Management, Self-Reflection, Multi-perspective Thinking);

5. **World View** (Global Awareness, Social Responsibility, Challenging the status quo, Sustainability Awareness, Environmental Awareness, General Knowledge, Lifelong Learning);
6. **Character and Ethical Orientation** (Respect for others, Open Mindedness, Agility, Adaptability, Curiosity, Empathy, Emotional Intelligence, Perseverance/Grit, Ethical Conscience, Personal Engagement).

All 53 competences are rated as being of at least some importance: with average ratings of **3** or more. The **range of average importance ratings** (all respondents) is **1.43**. Set 2 includes both highest (Problem Solving, 4.74) and lowest (Entrepreneurship, 3.31) competences. However, excluding Entrepreneurship which is an outlier, the next nearest competence is some 0.42 points higher (Economic Skills, 3.73); this reduces the range to **1.01**. This confirms that average importance ratings for all competences are high and in a relatively small range.

Table III includes the rank order of each competence (out of 53, with 1 ranked most important) and corresponding average importance score (1 to 5, where 5 is most important). The **five most important competences** overall have ratings greater than 4.5. They are: Problem Solving, Communication, Teamwork, Respect for Others and Critical Thinking.

Disaggregating results by category provides interesting insights. Whilst the specific competences ranked as most important by category are broadly similar, there are also notable differences such as: rank order and inclusion/ exclusion of certain competences by category.

TABLE III
RANK AND AVERAGE IMPORTANCE OF COMPETENCES BY CATEGORY – TOP FIVE

Competence Set Competence	**Ac** Rk Sc	**E-M** Rk Sc	**E-N** Rk Sc	**E-S** Rk Sc	**St** Rk Sc	**All** Rk Sc
2 Problem Solving	**1** **4.74**	**1=** **4.76**	*11* *4.40*	**1=** **4.81**	**1** **4.75**	**1** **4.74**
3 Communication	**5=** **4.54**	**1=** **4.76**	**1** **4.90**	**1=** **4.81**	**2** **4.69**	**2** **4.68**
3 Teamwork	**2=** **4.61**	**5=** **4.62**	**2** **4.80**	**1=** **4.81**	**4** **4.61**	**3** **4.64**
6 Respect for Others	**4** **4.57**	**3** **4.71**	*37=* *4.10*	*7* *4.57*	**3** **4.64**	**4** **4.60**
4 Critical Thinking	**2=** **4.61**	**5=** **4.62**	**3=** **4.70**	*10=* *4.43*	*6* *4.53*	**5** **4.56**
3 Collaboration	**5=** **4.54**	**4** **4.67**	*26=* *4.20*	**5=** **4.62**	*8* *4.45*	*6* *4.49*
4 Time Management	*31=* *4.13*	*36=* *4.10*	**3=** **4.70**	**5=** **4.62**	**5** **4.54**	*11* *4.42*
1 Technical Skills	*8* *4.48*	**5=** **4.62**	*11=* *4.40*	*14=* *4.38*	*13* *4.43*	*10* *4.45*
5 Sustainability Awareness	*7* *4.50*	*11=* *4.48*	**3=** **4.70**	*10=* *4.43*	*9=* *4.44*	*7* *4.47*
6 Adaptability	*11=* *4.35*	*15=* *4.38*	*26=* *4.20*	**4** **4.71**	*14* *4.42*	*12* *4.42*

Key: Ac=Academic, E-M= Employer-Multinational, E-N=Employer-National, E-S=Employer-SME, ST=Student. Rk=Rank, Sc=Average Score
Note: Cells in Table III with *black italic text* indicate ranks outside 1-5

Ten different competences feature in total across all categories. In most categories, there are more than five competences ranked in the top five as some share the same average importance scores.

Compared to overall rankings, academics rated the same five competences as most important though rank order differs. Academics also include Collaboration in the top five ranking. Students' top five most important competences broadly reflect overall results: with four competences in common though rank order differs. Time Management replaces Critical Thinking in their top five. Considering employers:

- Multi-national – rate the same five competences as most important as those rated most important overall as well as Collaboration and Technical Skills
- National – include three of five competences ranked most important overall in their most important competences. However, they exclude Problem Solving and Respect for Others which are ranked in the top five overall from their top five. Instead, Time Management and Sustainability Awareness are included in their top five.
- SMEs – include three of five competences ranked most important overall but exclude Respect for Others and Critical Thinking; however, Adaptability, Collaboration, Time Management are included in their top five.

For completeness, Table III includes rank order and average importance score for all competences in the table, not only those in the top five ranking for some categories. (For example, Respect for Others is in the top five for some categories, but not all. However, its rank and average importance score are included for all categories). It is evident that regardless of the rank order, all average importance scores are relatively high: the lowest in Table III is 4.10.

D. Importance of Competences by Competence Sets

Exploring lowest and highest importance ratings within each Competence Set yields further insights into similarities and differences between respondent categories. In fact, they demonstrate a lot of similarity (Table IV). In most Competence Sets, many categories rate the same competences lowest and highest, though ratings differ slightly.

In Set 1, Economic Skills are consistently ranked lowest whilst Technical Skills are consistently ranked highest by all but one category: Employers-National rate Research Skills lowest and Digital Skills highest (note: caveat that the number of responses is low). In Set 2, all categories rate Entrepreneurship lowest and Problem Solving highest.

Results are more mixed in Set 3: whilst most categories rate Communication as highest competence in this Set, academics are the exception, rating Teamwork highest. The lowest rated competences in this Set vary across categories with Conflict Management rated lowest by academics and Employers-SMEs (also rate Negotiation as joint lowest) whilst Intercultural Skills are rated lowest by Employers-National and Students. Interestingly, Employers-Multi-National rate Leadership as least important in this Set.

Turning to Set 4, three categories (academics, Employers-Multinational, Employers-National) rate Critical Thinking highest whilst Employers-SMEs and Students rate

Time Management highest. Three competences in this Set are rated as least important by various categories: Self Reflection (academics, Employers-Multi-national); Systems Thinking (Employers-National, Employers-SMEs); and Holistic Thinking (Students).

The most important competence in Set 5 is either Sustainability Awareness or Environmental Awareness in all categories. The least important competences are General Knowledge (Academics, Employers-Multinational), Global Awareness (Employers-National, Employers-SMEs) and Challenging the Status Quo (Students).

In Set 6, most categories rated Agility as the least important competence; the exception is Employers-SME which rates Ethical Conscience as least important. Across categories, there is a lack of consensus on the most important competence in this Set: Respect for Others is rated highest by Academics, Employers-Multinational and Students whilst Personal Engagement is rated highest by Employers-National and Adaptability is rated highest by Employers-SMEs.

The data in Table IV also demonstrate that differences between highest and lowest average importance ratings rated by each category of respondent exist, though typically small.

TABLE IV
IMPORTANCE RATINGS (LOWEST AND HIGHEST INDIVIDUAL COMPETENCE) BY COMPETENCE SET AND CATEGORY
(5-VERY IMPORTANT TO 1-NOT AT ALL IMPORTANT)

Competence Set (No. of Competences)	**Ac** **Lo** **Hi**	**E-M** **Lo** **Hi**	**E-N** **Lo** **Hi**	**E-S** **Lo** **Hi**	**St** **Lo** **Hi**
1 Fundamental Technical Skills (5)	Econ 3.70	Econ 3.57	Res'rch 3.80	Econ 3.62	Econ 3.75
	Tech 4.48	Tech 4.62	Digital 4.50	Tech 4.38	Tech 4.43
2 Application Skills (13)	Entrepr 3.46	Entrepr 3.24	Entrepr 3.10	Entrepr 3.14	Entrepr 3.30
	Prob Solv 4.74	Prob Solv 4.76	Prob Solv 4.40	Prob Solv 4.81	Prob Solv 4.75
3 Outward Facing – People Orientated Skills (8)	Conf Mgt 3.80	Leader-ship 3.95	Inter-cult 3.30	Conf Mgt 3.81 Negot 3.81	Inter-cult 3.85
	Team 4.61	Comm 4.76	Comm 4.9	Comm 4.81 Team 4.81	Comm 4.69
4 Inward Facing – Ways of Thinking (10)	Self Reflect 3.80	Self Reflect 3.86	Syst Think 4.00	Syst Think 3.76	Holist Think 3.45
	Critical Think 4.61	Critical Think 4.62	Critical Think 4.70	Time Mgt 4.62	Time Mgt 4.54
5 World View (7)	Gen. Knowl 3.85	Gen. Knowl 3.67	Global Aware 3.80	Global Aware 3.95	Chall StatQuo 3.74
	Sustain Aware 4.50	Enviro Aware 4.57	Sustain Aware 4.70	Sustain Aware 4.43 Enviro Aware 4.43	Sustain Aware 4.44 Enviro Aware 4.44
6 Character and Ethical Orientation (10)	Agility 4.00	Agility 4.10 Emp'y 4.10	Agility 3.70	Ethical Consc 4.00	Agility 3.85
	Resp others 4.57	Resp others 4.71	Pers Engage 4.60	Adapt-ability 4.71	Resp others 4.64

Key: Ac=Academic, E-M=Employer-Multinational, E-N=Employer-National, E-S=Employer-SME, ST=Student.
Lo/Hi=Lowest/Highest Average Importance Score in Set
Note: Refer to Section C earlier for Competence descriptors in full

These survey findings provide an understanding of stakeholder perceptions (amongst survey respondents) on the most important competences for engineers of the future to help solve the SDGs. Despite nuances in rank order by category of respondent, amongst survey respondents, the competences rated as being the most important are broadly aligned. So, survey respondents in all categories have similar perceptions about the most important competences for engineers in the context of addressing SDGs.

This convergence of perceptions of the most important competences is reassuring given the global nature of SDGs and the complementary and inter-connected roles that students, academics and employers play in responding to these. There is scope for engineering education programmes to reinforce and further develop these important competences.

Comparing and contrasting stakeholder perceptions does, however, reveal some degrees of difference. It is important that these are not overlooked so that in preparing students for the world of work, engineering education takes into account the somewhat differing priorities of different categories of employer, for example. There may be a role for greater industry/university collaboration to facilitate this.

IV. CONCLUSION

The survey findings offer a better understanding of stakeholder perceptions (amongst survey respondents) on awareness of SDGs and of the most important competences for engineers of the future to help solve the SDGs.

There are interesting differences in awareness of SDGs, highlighting scope to raise awareness further, particularly in NI and amongst employers and students. For students, this could be immediately addressed in the design of engineering education programmes. For employers, there is potential to identify (and learn from) effective initiatives to raise awareness.

There is broad agreement on the most important competences required by engineers though also differences of note. This is perhaps to be expected given different environments in which academics, employers and students operate.

It is notable that some competences (Communication, Teamwork) feature in all employer categories' top five, whilst there are also some differences. Thus, whilst there may be potential to focus on the most important (common) competences in the design of engineering programmes, there may also be merit in further research. That could validate and unpack reasons for differences between employer categories and also consider how to best to address varying requirements in engineering programmes.

Employer-Multi-nationals and Employer-SMEs also rate Problem Solving and Collaboration amongst the five most important skills. However, SMEs include Adaptability and Time Management in their top five too whereas Multi-Nationals include: Respect for Others, Critical Thinking and Technical Skills. This may reflect the differing nature of engineering roles in these organisations. Engineers in SMEs are likely to fulfil broad diverse roles (marketing, winning work, designing, invoicing) whereas in multi-nationals, they may have more focused, specific roles (thus Critical Thinking and Technical Skills are important).

In both categories, whilst Collaboration is important, this may also manifest itself in different ways: in SMEs, in a local context whereas in multi-nationals, across countries and across departments / functions.

Overall, these offer useful insights for the engineering education community by raising awareness of future-orientated thinking around sustainable development, the SDGs and the skills that engineers will require in this regard. Specifically, the analysis identifies opportunities for future development in engineering education, bearing in mind existing busy curricula. Academics may consider these findings in engineering curriculum design and in managing students' expectations to reflect employer priorities; employers may also consider their role and involvement in university/industry collaborations to support universities in the development of engineers for the future.

Further Research

Interrogating survey data by region and/or by gender may help to explain differences and similarities across the categories (academic/ employer/ student) such as: difference in awareness of SDGs; and whether similarities in importance of competences are consistent in sub-groups.

There is also scope to compare the survey findings with local accreditation criteria (defined by relevant accrediting bodies: Engineers Ireland (EI) and Engineering Council UK (EC), respectively). EI has updated accreditation criteria for the bachelor's degree in engineering to reflect best practice in sustainability education. Seven Programme Areas define what students should learn, understand or appreciate as a result of their studies. With one full Programme Area focused on sustainability, it is clear that engineers play a critical role in delivering on sustainable development and the SDGs nationally and internationally (Engineers Ireland [9]). The EC in the UK has also updated its accreditation criteria (fourth edition) to include more of a focus on inclusive design and innovation, sustainability and ethics and equality, diversity and inclusion (Engineering Council, UK [10]).

Further analysis could examine other data collected in the survey: preparedness of graduates and priorities for teaching overall and disaggregated by categories considered in this paper. Building on this research, further data collection and analysis could be undertaken to overcome research limitations described in this paper.

Conflict of Interest

The authors declare no conflict of interest in submitted work.

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