INTELLECTUAL OUTPUT 1 (IO1): SKILLSFOCUS 2030: A MODEL OF SKILLS AND ATTRIBUTES NEEDED FOR ENGINEERS TO ACHIEVE THE SDGS

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Contents

Executive Summary

This Intellectual Output (IO1) document reports on the outcomes of Activity 1 as part of the A-STEP 2030 (Attracting diverSe Talent to the Engineering Professions of 2030) project. This project is an EU Erasmus + project funded under call number 2018-1-FR01-KA203-047854. The document begins by explaining the purpose and aims of the overall research project and more specifically, the research questions associated with Activity1. Two tasks were completed in order to contribute to this report, the first being a literature review (Tabas, Beagon and Kovesi, 2019) and the second consisting of 12 focus groups (three in France, Ireland, Finland and Denmark), the findings of which are detailed in Beagon et al., (2019). Both reports are available on the project website https://www.astep2030.eu/en.

The report summarises the outcomes of both studies and presents a model of skills and attitudes required of engineers in the future in order to meet the Sustainable Development Goals (SDGs). The model is presented in tabular form and has three key pillars; Technical skills, Non-Technical Skills and Attitudes. These are further spilt into categories with lists of skills sets under the following terms: Fundamental Technical Skills, Application Skills, Outward Facing – People Orientated Skills, Inward Facing – Ways of Thinking, Worldview and Character and Ethical Orientation. The Model is presented on page 11.

The findings present a picture of the future engineer as having a broad worldview, a sound character and a strong ethical orientation. Engineers still need to be taught the technical and application skills required to achieve engineering projects, but non-technical skills will be equally important in their education. Compared to traditional approaches to engineering education, this new approach to engineering places a relatively high value on social values and ways of thinking and the importance of the human and social dimensions in engineering practice.

2.0 Summary of Overall Research Project

The main objective of the A-STEP 2030 project is to develop new and innovative teaching approaches relevant to learners' values yet appropriate to teach a new set of skills and competencies needed for the future. Our goal is to create an attractive and fascinating learning environment thereby encouraging young people and adult learners with diverse backgrounds to engage in engineering studies and the profession as a whole. The project comprises the following three activities:

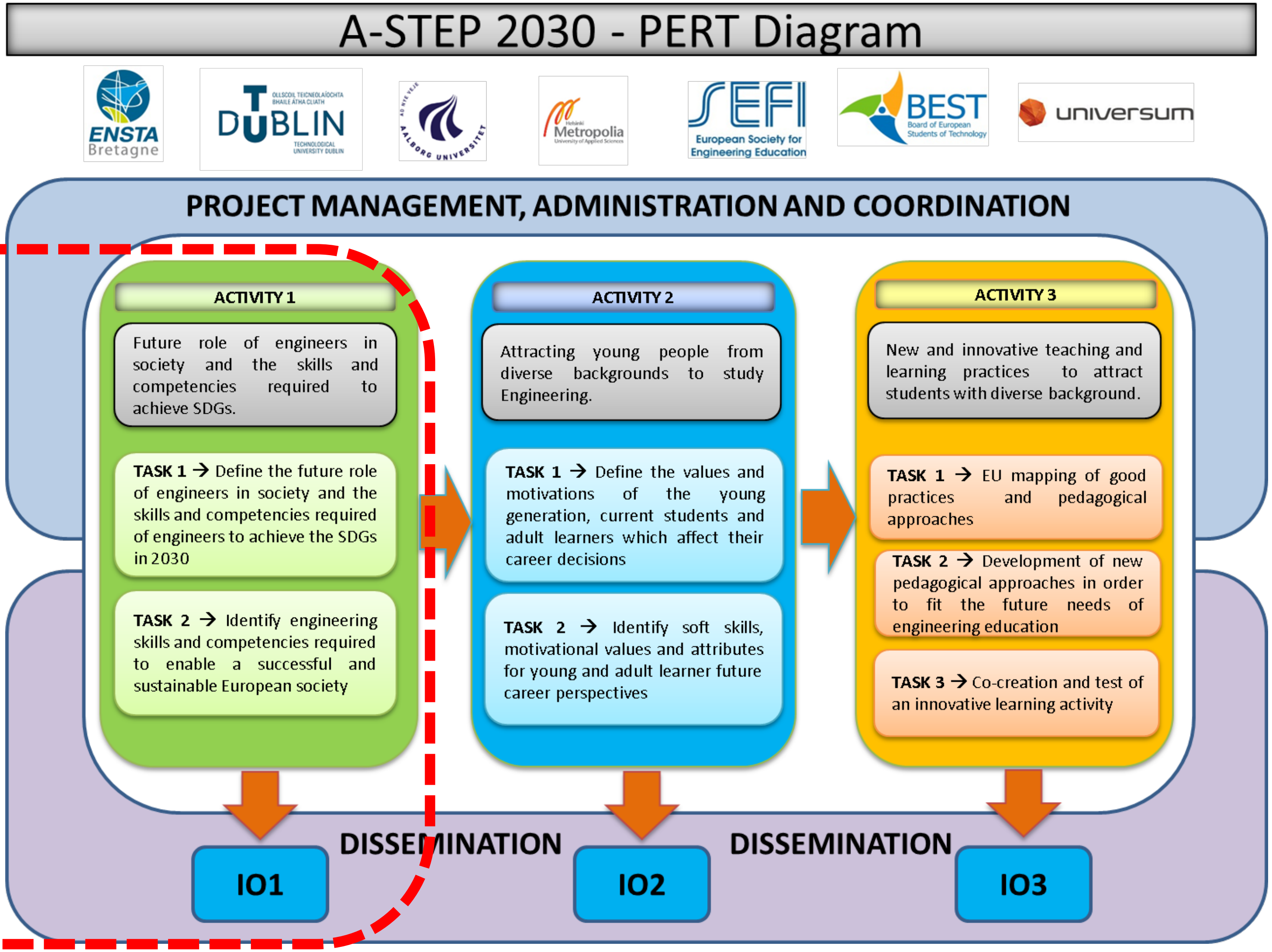
Activity 1: Determine future roles and skills requirements of engineers to enhance the sustainable development of society.

Activity 2: Investigate the values and motivations of young people, students and adult learners to determine how this influences their future career choices and use this knowledge to make a career in engineering more attractive to all young people.

Activity 3: Develop new and innovative teaching and learning practices to respond to these findings.

The project consortium has 7 members from six EU countries (France, Denmark, Finland, Ireland, Sweden and Belgium) and 10 associated partners. The team includes four different European HEIs all involved in Engineering Education Research. (ENSTA Bretagne, France, TU Dublin, Ireland, Aalborg University, Denmark and Metropolia University, Finland.) The team is also complemented by representatives from SEFI and BEST (Board of European Students of Technology) which represents HEI students in STEM, and Universum - experts in research relating to student motivations and career choices.

Figure 1 shows the main activities associated with the project. This report focuses on the result of Activity 1: Future role of engineers in society and the skills and competencies required to achieve the SDGs.



The outcomes of this Activity are the focus of this report (IO1).

Figure 1: Overall Project details showing the aims of each activity.

3.0 Research Questions

The purpose of Activity 1 was to both define the role and skills requirements of engineers in the future. This was achieved by undertaking a literature review and gathering insights from varied actors in the form of Engineering Academics, Engineering Students and Engineering Employers in each of four countries: France, Ireland, Denmark and Finland.

The overall research questions associated with this activity were;

Research Question 1: What are the future professional roles of engineers in relation to the global issues facing our society?

Research Question 2: What are the skills that engineers need to resolve the UN SDGs?

4.0 Literature Review Process

The literature review method comprised collecting articles related to the following five topics in line with all three activities:

- Sustainable development,
- Sustainability and diversity,
- The Role of Engineers in achieving the SDGs
- Attractiveness of Engineering Education and
- Future skills and competencies in relation to sustainable development.

Peer reviewed scientific journal articles, conference papers, scientific books and reports published within the last 15 years were considered. The search made use of scientific journal databases (e.g.: Science Direct, ERIC), library catalogues and subject specific websites (e.g.: EE publications on the SEFI website).

The full outcome of the literature review is presented in Tabas, Beagon and Kovesi (2019) however, only those topics relevant to Research Question 1 are summarised in this report.

5.0 Focus Group Process

Each partner country undertook three focus groups, with engineering employers, engineering academics and engineering students. A summary of participants in the Focus Groups, their level of expertise and their type of discipline are all described in the detailed focus group report (Beagon et al., 2019). In total there were 86 participants who engaged in focus groups as part of this study.

It is important in any research work that involves human participants that researchers are mindful of the potential impact of the data collection on any participant. Ethical approval was granted by the TU Dublin Research Ethics and Integrity Committee on 18th May 2019: Reference: REC-18-184. Each partner also gained ethical approval for their focus groups in their respective Institutions.

Each partner created a report summarising the findings of the focus groups in each country, using an agreed report template. This was forwarded to the lead partner in this activity and formed the basis of the overall focus group report (Beagon et al., 2019).

6.0 Research Question One: What are the future professional roles of engineers in relation to the global issues facing our society?

6.1 Literature Review Findings

The literature is nearly unanimous in finding that engineers will have a leading role to play in the project of attaining the sustainable development goals. Yet it is also the case that in order to fulfil the promise of their profession the engineers of the future will have to assume different social roles than they have up until the present. Traditionally, the engineer has been seen as primarily engaged in the service of industry. Pursuing sustainable development, however, will require that engineers serve society and the environment (the two other pillars of sustainable development's triple bottom line). Others have called out for engineers to play a leading role in addressing various social issues, from what Paul Smith Lomas (RAE, 2017) has called "technology injustice" to gender inequality (Wacjman, 2010; Falkner, 2001) This will require new skill sets, but it will above all require new ways of carrying out engineering projects. According to Halbe (2015), the engineer of the future will need to shift from seeking basically technical solutions to integrated, adaptive, and participatory ones. This means that the role of the engineer will not be so much that of knower and problem-solver as orchestrator of collective problem-solving performances. In order to play this role, engineers will need accept a role in which they are not merely responsible for developing and implementing new technologies, but are also involved in education, communication and mediation. The WFEO (2016), for example, has insisted that engineers must take a role at the table in international and local policy discussions related to development. Mair (2018) has called on engineers to not only solve problems but to "inspire" change and to take up a role as leaders and change-makers. Chukwul et al (2014) suggest that engineers need to be "enlighteners."

As Katehi (2005), Annan-Diab and Molinari (2017) and Halbe (2015) have pointed out, the global scale of the SDGs as well as the increasing diversity of modern societies implies that dealing with diversity will play an increasing role in the future of the engineering profession. Recent work on solving high-level problems such as sustainable development has highlighted the potential value working in diverse teams (Page 2017), suggesting that diversity may be less a barrier than an opportunity with respect to achieving sustainability. The impact on the role of future engineers is that they will need to become specialists in what Lambrects et al, (2019) describe as "using diversity," taking a leading role in integrating diversity into their organizations. In addition to dealing with cultural and ethnic diversity, some envisage greater diversity at the level of engineering competences and skill sets. Goldberg and Summerville (2014), commenting on the development of the curriculum at Olin College of Engineering, have suggested that future engineers will need not only analytic intelligence, but design, linguistic, people, body, and mindful intelligence. Such skill differentiation will obviously be accompanied by a diversification of the roles played by engineers within their organizations and within society at large.

The Brundtland report (1987) defined sustainability as "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." It should thus be unsurprising that many authors foresee the future roles of the engineer as inseparable from exercising foresight. Lambrects et al (2019) and Rogers, 2018; Ratliff, 2018 all claim that foresight thinking and related abilities such as systems thinking will characterize all future engineering projects. As (see Costanza et al, 2007) have pointed out, caring for the future also requires that engineers have knowledge of the past, in particular of the history of interactions between natural and social systems. Relatedly, Ramifard and Trollman (2018) have claimed that the roles occupied by future engineers will need to be more grounded in understanding the "real life" impacts of technologies on society.

Overall, the picture that emerges from the literature suggests that the role of the engineer in the future will be broader than at present, and far more entangled in issues of social and environmental concern. Tomorrow's engineer will not only solve problems but will additionally assume a leading role in foreseeing future problems and mobilizing collective solutions to these challenges.

7.0 Research Question Two: What are the skills that engineers need to resolve the SDGs?

7.1 Focus Group Findings

The focus groups were tasked with a brainstorming session which identified a list of skills required to achieve the SDGs. Figure 2 shows the word cloud and list of most frequently used phrases associated with all participant groups and all countries. Further details of skills requirements differentiated by each particular group and country are available in Beagon et al., (2019).

Figure 2: Overall word cloud indicating skills requirements for Engineers to achieve the SDGs [All groups, All countries]

8.0 A Model of Engineering Skills Requirements to achieve the SDGs.

The final section of this report presents a Model of Engineering Skills required to achieved the SDGs. This model was created by using the key words which emerged from the focus group findings. This section begins by explaining the methodology for how the model was developed and is completed by the team's proposal for a new Model of Engineering Skills and Attributes for Engineers to solve the SDGs.

8.1 Methodology for Model Development

Figure 3 outlines the methodology of how the model was developed to ensure validity and reliability of the findings.

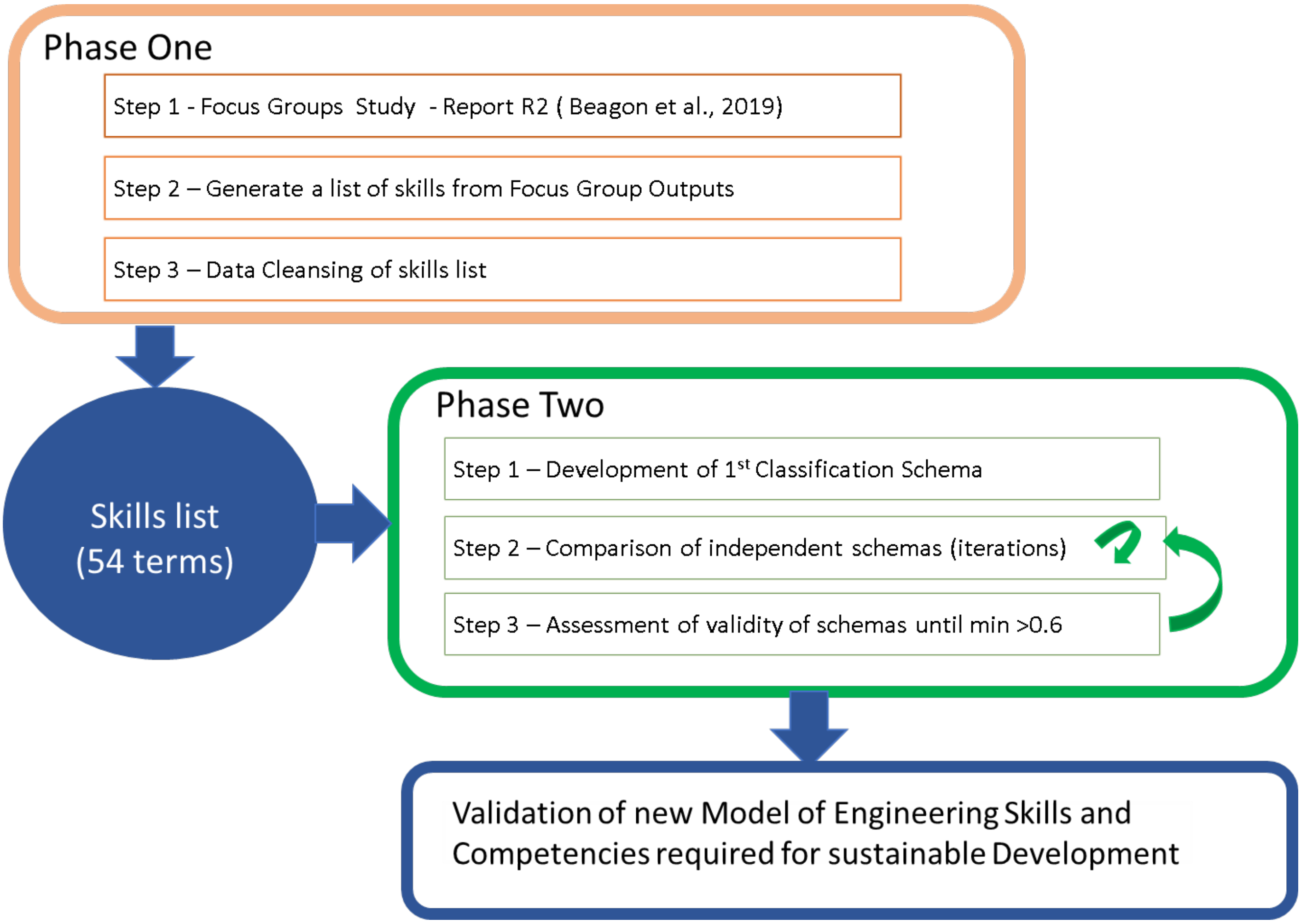


Figure 3: Process for creation of model

8.2 Phase One (Skills list from Focus Groups)

The aim of the first phase was to generate a set of skills and competencies which were gathered from the focus groups with engineering students, academics and employers in four countries in Europe. The results of the focus groups are recorded in the second report from the project (Beagon et al., 2019).

All skills and competencies listed by all the focus groups were combined into one list which resulted in a total of 266 terms. The data was then cleansed in the three steps in Table 1. Some examples are provided here for clarity.

Table 1: Data cleansing steps undertaken with original skills list

Step	Description	Example	No of terms remaining on list
1	Each phrase raised by the focus groups (266) was split into individual words resulting in 599 terms	"Need to interpret or validate solutions" becomes "Need" and "to" and "interpret" and "or" and "validate" and "solutions"	599 terms
2	Words which do not relate to skills specifically were deleted. Words which were similar but with a different declension or with similar meaning were assimilated.	"Need", "to", "or" were deleted. "interpret" was moved to "interpreters" as this term had been mentioned several times.	444 terms
3	The terms were reviewed again through three iterations to condense the categories assimilating similar terms. This involved a stage of interpretation by the researcher.	For example "Personal Engagement" and "Agency" were combined into one term "Personal Engagement and Agency" "Maths" was allocated to "Technical Skills" "Questioning" was incorporated within "Critical Thinking"	Round 1: 139 Round 2: 117 Round 3: 54

Phase one resulted in a final list of 54 terms, identifying the skills required of engineers to meet the SDGs.

8.3 Phase Two (Creation of Model)

The purpose of the second phase was to develop a coherent and comprehensive model of the skills list generated in the first phase. This phase consisted of three steps. In step one, two researchers independently reviewed the data pool of 54 skills obtained in the first phase. The purpose of this review was to create a functional classification scheme consisting of:

- the definition of the classification structure,
- the description and labelling of the main categories and
- the creation of subcategories with a label clearly describing the content/items.

The second step compared the independently created categorisation schemas and through discussion and dialogue, one common categorisation schema was agreed and validated by the two researchers. The work included a discussion on the degree of similarity and differences between the independently created schemas, a discussion of the terms used to describe each category and final convergence of the categorisation schemas.

This agreed scheme was then discussed with another researcher involved in the project and this resulted in a further iteration of the model.

The third step consisted of the assessment of the validity of the newly developed model by the involvement of two independent researchers, without knowledge of the project details. Two engineering education PhD students were asked to put all the items into a suitable category and to report if there were any difficulties or hesitations with the category assignments.

The researchers then analysed the level of interrater agreement for each reviewer compared to the previously agreed model. The aim was to achieve an overall interrater agreement of 0.6. On the first round, the agreement was calculated at 0.67 and 0.6.

The commentary provided by each independent reviewer was then analysed and final changes made to the model. With the final changes, the second round of interrater agreement provided results of 0.71 and 0.64 which was deemed to have met the requirement of > 0.6 and indicates that the newly created model for skills is validated.

It is important to note that whilst the original intention was to create a Model of Skills for Engineers to solved the SDGs, the outcome of the study indicated that the ethical values and character of the individual was a key concern. Therefore it was proposed to rename the output as "Model of Skills and Attributes of Engineers to meet the SDGs".

8.4 Model of Engineering Skills and Attributes required to meet the SDGs.

The proposed model is presented in Figure 4.

Technical Skills		Non-Technical Skills		Attitudes	
Fundamental Technical Skills	**Application Skills**	**Outward Facing – People Orientated**	**Inward Facing – Ways of Thinking**	**World view**	**Character and Ethical Orientation**
Mathematics Skills Digital Skills Economic Skills Research Skills Technical 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 Problemisation	Inter Cultural Skills Collaboration Leadership Conflict Management Negotiation Communication Foreign Languages Listening Respecting Diversity Teamwork Inter Cultural Skills	Critical Thinking Life cycle thinking Holistic Thinking Systems thinking Creativity Analytical Thinking Stress Management Time Management Self Reflection Multi-perspective consideration	Global Awareness Social Responsibility Challenging the status quo Sustainability Awareness Environmental Awareness General Knowledge Lifelong Learning	Respect for others Open mindedness Agility Adaptability Flexibilty Curiosity Empathy Emotional Intelligence Perserverance/Grit Ethical Conscience Personal engagement and agency

Figure 4. Model of Engineering Skills and Attributes required to meet the SDGs

9.0 Conclusions

The literature review presented a picture of an engineer in the future needing a suite of skills, which go far beyond traditional engineering technical skills. The role of the Engineer will move from serving industry to serving society and this requires engineers to be mindful of the impact of their decisions on both society and the environment. Engineers will need new ways of carrying out engineering projects and will need to have greater influence at higher levels of political power. They can no longer focus only on the technical aspects of projects, they are called to look up, face the future and become changemakers in society. By looking upward and outward, they need to have a sustainable worldview, one that acknowledges international and intercultural issues, the diversity of society, and understands how to turn these seeming liabilities into opportunities. Engineers of the future will be presented with complicated, complex problems and will need to consider multi-perspective views, whilst being conscious of long-term effects, risk and the impacts of decisions on society. These engineers will most certainly need fundamental technical skills, but as the rate of change in technology increases, engineers must also become highly flexible lifelong learners, capable of adapting their practices to new technologies and developments. With all of these new challenges comes the awareness that Engineers of the future will need to know how to work with diverse others and with difference in general, will need to understand how to make the most of teams comprising non-engineers, composed of people speaking languages and of different nationalities. These attributes are those which must form the character and the practice of the engineer of the future.

It is worth noting that while the participants in our focus groups were clearly interested in systems thinking and lifecycle assessments, in other words in gaging and mastering the externalities associated with engineering in general and innovation in particular, they did not follow the literature in placing emphasis on importance of foresight capacities such as scenario thinking, imagineering, simulation play, future literacy and the like. This is surprising both given their prevalence in the literature and the emphasis placed upon the importance of developing these capacities in EU publications associated with the Horizon 2020 Responsible Research and Innovation Initiative, which has called for "the introduction of broader foresight and impact assessments for new technologies beyond their anticipated market-benefits and risks" (Von Schumberg 2013). Nevertheless, it is worth questioning whether this oversight stems from a studied rejection of the efficacy of these assessment technologies on the part of the participants in the focus groups or whether (and more likely) it derives from a lack of awareness of the very existence of these tools stemming from their relative novelty and lack of diffusion within current engineering curricula. In either case, practices drawn from experimental future-based pedagogy such as York and Conley's FuturesLab model may well be worth integrating into later phases of this project, despite silence of the focus groups relative to the importance of these anticipation skills (York et al., 2019).

The model that we are presenting offers a broad picture of a person with an expansive worldview, a sound character and a firm ethical orientation derived from a commitment to and belief in the idea that engineering can be used to further sustainable development. Building on these characteristics, the student engineers of the future will need to master technical tools such as mathematics, as well as a broad pallet of application skills that will allow them to find ways of applying fundamental tools to the practice of achieving sustainable engineering projects. Throughout their education—and indeed throughout their life-long learning—tomorrow's engineers will also acquire non-technical skills of two primary types: what we have described as inward facing and outward facing. The first of these involves capacities like creativity and critical thinking, both of which will be necessary for the kind of responsible research and innovation that will be characteristic of the practice of tomorrow's engineers. The latter, outward facing skills, will involve people skills of all types, with a particular emphasis on those relating to dealing with diversity, inclusion, and difference.

Overall, tomorrow's engineer will be both better grounded in the urgency of using engineering to bring about sustainable development and better prepared, both in technical and in human terms, for making sustainable development a reality.

10.0 Acknowledgements

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11.0 References (Chicago)

ALLEA. "The European Code of Conduct for Research Integrity". (2017) Available from; http://ec.europa.eu/research/participants/data/ref/h2020/other/hi/h2020-ethics_code-of-conduct_en.pdf. Accessed 7th October 2017.

Annan-Diab, Fatima, and Carolina Molinari. "Interdisciplinarity: Practical approach to advancing education for sustainability and for the Sustainable Development Goals." *The International Journal of Management Education* 15, No. 2 (2017): 73-83.

Beagon, U., Kövesi, K., Gillet, C., **Nørgaard**, B., Spliid, C., Lehtinen, R., Piirronen, A. (2019), "Report on outcomes of focus groups held in Ireland, France, Denmark and Finland on the skills required of engineers in the future", Second Project Report, A-STEP 2030 project, pp. 1-46

Brundtland, Gru, Mansour Khalid, Susanna Agnelli, Sali Al-Athel, Bernard Chidzero, Lamina Fadika, Volker Hauff et al "Our common future (\'brundtland report\')." (1987).

Chukwu, Promise U., et al "Sustainable energy future for Nigeria: the role of engineers." *Journal of Sustainable Development Studies* 6, No. 2 (2014).

Costanza, Robert, Lisa Graumlich, and William L. Steffen, eds. *Sustainability or collapse?: An integrated history and future of people on Earth*. Mit Press, 2007.

Faulkner, Wendy. "The technology question in feminism: A view from feminist technology studies." *Women's studies international forum*. Vol. 24. No. 1. Pergamon, 2001.

Halbe, Johannes, Jan Adamowski, and Claudia Pahl-Wostl. "The role of paradigms in engineering practice and education for sustainable development." *Journal of Cleaner Production* 106 (2015): 272-282.

Katehi, Linda. "The global engineer." *Educating the engineer of 2020: Adapting engineering education to the new century*, (2005): 151-155.

IUA. "National Policy Statement on Ensuring Research Integrity in Ireland" (2014). Available from; http://www.iua.ie/wp-content/uploads/2014/06/National-Policy-Statement-on-Ensuring-Research-Integrity-in-Ireland-2014.pdf. Accessed 7th October 2017.

Lambrechts, Wim, et al "The role of individual sustainability competences in eco-design building projects." *Journal of Cleaner Production* 208 (2019): 1631-1641.

Rahimifard, Shahin, and Hana Trollman. "UN Sustainable Development Goals: an engineering perspective." (2018): 1-3.

RAE, (2017) https://www.raeng.org.uk/publications/other/engineering-a-better-world-brochure.

Ratcliffe, John. "Imagıneering Sustaınable Cities: Usıng Foresıght Through Scenarıos To Future Proof Present City Plannıng Policy." *Proceedings: Strategies For A Sustainable Built Environment, Pretoria* (2000): 1-12.

Rogers, Chris DF. "Engineering future liveable, resilient, sustainable cities using foresight." *Proceedings of the Institution of Civil Engineers–Civil Engineering*. Vol. 171. No. 6 (2018).

Tabas, B., Beagon, U. and Kövesi, K. (2019), "Report on the future role of engineers in the society and the skills and competences required for engineers", First Project Report, A-STEP 2030 project, pp. 1-40.

Von Schomberg, Rene (2013). "A vision of responsible innovation". In: R. Owen, M. Heintz and J Bessant (eds.) *Responsible Innovation*. London: John Wiley, 2014.

Wajcman, Judy. "Feminist theories of technology." *Cambridge journal of economics 34*, No. 1 (2010): 143-152.

WFEO (2016) http://www.aaes.org/sites/default/files/WFEOENGINEERSFORASUSTAINABLEPOST2015%20V1.6.pdf.

York, E., Conley, S., Kodua, S. "The STS Futures Lab at James Madison University: Integrating Design Fiction, Experimental Pedagogy, and Anticipatory Research into STEM Education and Outreach" *CIRCE: STEAM Edition*. Editors: Gillian Judson & Jailson, Centre for Imagination in Research, Culture & Education. Simon Fraser University. 2019 (https://sites.lib.jmu.edu/stsfutureslab/)