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RESEARCH ARTICLE

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Preparing engineering students for the challenges of the SDGs: what competences are required?

Una Beagon [a], Klara Kövesi[b], Brad Tabas[b], Bente Nørgaard[c], Riitta Lehtinen[d], Brian Bowe [a], Christiane Gillet[b] and Claus Monrad Spliid[c]

[a]Technological University Dublin, Dublin, Ireland; [b]ENSTA Bretagne, Brest, France; [c]Aalborg University, Aalborg, Denmark; [d]Metropolia University, Helsinki, Finland

ABSTRACT

Despite the emerging discussions about the growing role of engineers in achieving the Sustainable Development Goals (SDGs), there is a lack of agreement on which competences should be prioritised to prepare engineering students to resolve future sustainability challenges. This study examined and compared the views of key stakeholders of engineering education (Academics, Employers and Students) using twelve focus groups in Denmark, Finland, France and Ireland. The findings were mapped against competences identified in previous studies to highlight gaps and opportunities for development. The results confirm the strong emphasis on normative, strategic and systems thinking competences in engineering. However, the outcomes also lack acknowledgement of anticipatory competence, contradicting the future oriented perspective required to achieve sustainable development. The findings can be used by educators to inform programme development and to implement opportunities for students to develop the competences necessary to support sustainable development and the SDGs.

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Introduction

What will the engineer of tomorrow look like? How will they be trained and what competences will they need? Engineering problems are becoming more complex and multifaceted, often termed 'wicked' problems (Guerra 2017; Yearworth 2016; Lönngren and Svanström 2015). Future generations of engineers will not only be catalysts of technical innovation but will also play a leading role in addressing various social issues (Desha and Hargroves 2014). They will need to apply a holistic view, considering concepts such as context, complexity, uncertainty, risk or ethics (Byrne and Mullally 2014). The framework of the Sustainable Development Goals (SDGs) offers an opportunity to consider the competences needed of tomorrow's engineers (UN 2015). The 17 objectives of the UN 2030 Agenda for Sustainable Development can be considered as a formalised reference for achieving environmental, social and economic sustainability. The SDGs include 169 targets which relate to sustainability challenges in various domains (e.g.: developing sustainable cities and communities, providing clean water and affordable clean energy, combating climate change, promoting inclusive and sustainable industrialisation, providing quality education, eradicating extreme poverty, reducing of inequalities, etc.). These sustainability challenges call for future engineers

CONTACT Una Beagon una.beagon@tudublin.ie
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who are able to deal with these ill-defined, open-ended, cross-disciplinary, complex socio-technical problems (Tejedor et al. 2021; UNESCO 2021). Thus, in order to deal with these complex and global societal challenges, future engineers need to be equipped with a new set of competences.

The purpose of this study is to offer a momentary insight into the views of engineering students, engineering academics and engineering employers. We wish to identify a list of competences and compare the outcomes to published literature, but also to compare and contrast stakeholder views. Three key stakeholders were chosen to provide distinctive yet valuable perspectives. Firstly, employer views; companies that are working directly on providing sustainable projects, to identify what competences their employees need to address these pertinent issues. Secondly, views from academics who deliver engineering programmes are also of value. They provide an objective view which may not be influenced by concerns about profit or market share. They also have direct control over curricula and hence if there is a dissonance with employer views, there may be a mismatch of competences developed in engineering programmes. Finally, the study also considered students' views to determine their level of awareness of the competences required. Thus, in this comparison exercise we aim to identify gaps so that we can then provide suggestions for implementation in engineering curricula to better prepare engineering students for the future.

The key research questions addressed in this study were:

- What do key stakeholders of engineering education perceive are the competences that engineers need to support the SDGs?
- How do the competences identified in this study context compare to the 'Key competencies for sustainability' published in UNESCO (2017) and more recent literature?
- What are the differences, if any, between the perceptions of engineering academics, engineering students and engineering employers in relation to the competences required of engineers to support the SDGs?

Engineering education for a sustainable future

Over the last few decades, there has been an increasing demand to embed sustainability and sustainable development issues in engineering education (Segalàs Coral, Drijvers, and Tijseen 2018). The terms 'sustainability' and 'sustainable development' (SD) are often used interchangeably (as synonyms) and have no universally agreed meaning (Klotz et al. 2014; Byrne et al. 2010). In this study, we define sustainability as a long-term goal 'in which environmental, societal and economic considerations are balanced in the pursuit of an improved quality of life'[1] and sustainable development (SD), as the 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED 1987, 41). Education for Sustainable Development (ESD) is 'commonly understood as education that encourages changes in knowledge, skills, values and attitudes to enable a more sustainable and just society for all' (UNESCO 2017, 7) and is viewed as fundamental to addressing the complex challenges facing our contemporary societies.

More specifically, Engineering Education for Sustainable Development (EESD) requires a holistic and transformational approach, with the implementation of novel strategies and adequate pedagogical approaches (Romero et al. 2020). Kolmos, Hadgraft, and Holgaard (2016) identified three response strategies to EESD: (1) the add-on strategy, (2) the integration strategy and (3) the re-building strategy requiring a shift in the educational paradigm by emphasising values, identity and commitment. Moving specifically to pedagogical approaches, there is general agreement on the implementation of active learning approaches (Quelhas et al. 2019; Tejedor, Martí, and Segalas 2019a; Thürer et al. 2018; Guerra 2017; Holgaard et al. 2016) such as problem-based learning, project-oriented learning, case-based learning, solution-oriented learning, challenge-based learning, service learning or simulation as the most appropriate to help develop competences in EESD. Recent work has also shown the value in mapping out degree programmes to show the link between the specific learning objectives of SD defined by UNESCO (2017) with the learning outcomes of specific degree programmes. A recent Spanish engineering education project (EDINSOST) created a 'Sustainability Competency Map' (Segalàs and Sánchez Carracedo 2020; Albareda-Tiana et al. 2020) which is proposed as the first valuable step to meet the objectives of EESD.

Sustainability competences

According to a recent literature review on the changing role of engineers in society (Tabas et al., 2019) it broadly recognised that future roles require new competences for graduate engineers. However, there is a lack of consensus in the educational literature regarding the relevant competences that engineers will require (Shephard, Rieckmann, and Barth 2019; Mulder 2017).

In this study, we define competences 'as the knowledge, skills, abilities, attitudes, and other characteristics that enable a person to perform skillfully (i.e. to make sound decisions and take effective action) in complex and uncertain situations such as professional work, civic engagement, and personal life' (Passow 2012, 97). Moreover, guided by Bianchi (2020), we use the term competence (singular) and competences (plural) in this paper, except when different terms are drawn directly from the literature. Moving a step further, there is also an ambiguity in the definition of 'competences for sustainable development' and 'key competences in sustainability' (Bianchi 2020). The term 'key competences in sustainability' will be used in this study and are composed of several competences that are related to each other and viewed 'as a distinctive and multifunctional competency' (Brundiers et al. 2021, 17).

The work of Wiek, Withycombe, and Redman (2011), founded on a comprehensive literature review, is undoubtedly the most frequently cited and debated 'key competencies [*sic*] framework' in the academic literature on sustainability education. Numerous studies used this framework as a basic theoretical background, and so a certain degree of convergence can be observed in other studies (Bianchi 2020). Viewed as a reference framework in sustainability education, it initially included the following five competences: *systems thinking competence, anticipatory competence, normative competence, strategic competence and interpersonal competence* (Wiek, Withycombe, and Redman 2011). Rieckmann (2012) proposed extending this framework with several additional sustainability competencies [*sic*] as a result of a Delphi study with international experts. He highlighted *critical thinking* and *integrated problem solving* as competences necessary to enhance sustainability and Wiek also supplemented his previous findings to include *integrated problem solving* (Wiek et al. 2016).

We began our study by focusing on Wiek, Withycombe, and Redman's (2011) seminal work and undertook a literature review to identify more recent research (2011–2021) which complements the findings of the original Wiek, Withycombe, and Redman (2011) framework. Several additional sustainability competence clusters were identified and these are categorised and summarised in Table 1.[2]

Leaving behind literature on sustainability competences in general and turning our focus to competences specifically related to achieving the Sustainable Development Goals, led us to the seminal UNESCO (2017) report entitled 'Education for Sustainable Development Goals – Learning Objectives'. This report was based on related research works mentioned earlier (Rieckmann 2012; Wiek, Withycombe, and Redman 2011; De Haan 2010), and proposes a key competences framework specifically relevant to SDGs. It includes eight cross-cutting competences presented in conjunction with specific learning objectives for the SDGs. In addition to the key competences identified by Wiek, Withycombe, and Redman (2011), three additional competences are proposed: *critical thinking*, *self-awareness* and *integrated problem-solving*. The UNESCO (2017) framework was recently applied by Rosén et al. (2019) to evaluate the relevance of the CDIO Syllabus[3] to enhance EESD so can provide a useful benchmark for programme design.

The literature review also considered engineering education studies in particular and the range of competences identified. Thürer et al. (2018) advises that *problem solving* must be considered in a broader way: not focusing on providing solutions in a specific scientific field, but to consider

Table 1. Additional (to Wiek, Withycombe, and Redman 2011) competences in sustainability identified in the literature (2011–2021).[a]

Competence	Authors
Critical thinking	Rieckmann (2012), Guerra (2017), Kioupi and Voulvoulis (2019), Rieckmann (2018), Olalla and Merino (2019), Quelhas et al. (2019), Lozano et al. (2017), Vare et al. (2019), Trad (2019), Glasser and Hirsh (2016), Evans (2019), UNESCO (2017).
Intrapersonal competence	Rieckmann (2012), Lozano et al. (2017), Rieckmann (2018), Giangrande et al. (2019), Kioupi and Voulvoulis (2019), Redman (2020), Ortiz-Marcos et al. (2020), Pacis and VanWynsberghe (2020), Brundiers et al. (2021), Glasser and Hirsh (2016) UNESCO (2017).
Integrated problem solving	Thürer et al. (2018), Rieckmann (2018), Olalla and Merino (2019), Quelhas et al. (2019), Redman (2020), Pacis and VanWynsberghe (2020), Brundiers et al. (2021), Kioupi and Voulvoulis (2019), UNESCO (2017)
Empathy and change of perspective	Rieckmann (2012), Lambrechts et al. (2013), Lozano et al. (2017), Kioupi and Voulvoulis (2019), Olalla and Merino (2019), Trad (2019), Pacis and VanWynsberghe (2020), Ortiz-Marcos et al. (2020), Vare et al. (2019), Glasser and Hirsh (2016), UNESCO (2017)
Interdisciplinary work[b]	Rieckmann (2012), Lambrechts et al. (2013), Lans, Blok, and Wesselink (2014), Lozano et al. (2017), Guerra (2017), Olalla and Merino (2019), Quelhas et al. (2019), Heiskanen, Thidell, and Rodhe (2016), Giangrande et al. (2019).
Continuous learning[b]	Trad (2019), Demssie et al. (2019).
Implementation competence[b]	Heiskanen, Thidell, and Rodhe (2016), Redman (2020), Lambrechts et al. (2013), Quendler and Lamb (2016), Demssie et al. (2019), Pacis and VanWynsberghe (2020), Olalla and Merino (2019), Brundiers et al. (2021), Lans, Blok, and Wesselink (2014)
Transdisciplinarity[b,c]	Demssie et al. (2019), Evans (2019), Vare et al. (2019), Trad (2019).
Fundamental disciplinary competence[b]	Olalla and Merino (2019), Demssie et al. (2019), Redman (2020), Heiskanen, Thidell, and Rodhe (2016), Guerra (2017), Giangrande et al. (2019).

[a]Only those competences which are in addition to the Wiek, Withycombe, and Redman (2011) framework are presented in this table.
[b]Please note that these competences were NOT identified in UNESCO (2017).
[c]We have separated inter- and transdisiplinarity into two categories to acknowledge the difference in professional practices either between or beyond disciplines.

environmental, economic, social or ethical questions and constraints. Consequently, engineering students need to develop not only fundamental *disciplinary,* but also *multidisciplinary, interdisciplinary and transdisciplinary*[4] competences (Fitzpatrick, Byrne, and Gutiérrez Ortiz 2021; Guerra 2017; Felgueiras, Rocha, and Caetano 2017) and there is evidence that these have been afforded greater importance more recently (Tejedor et al. 2019b). Interdisciplinary projects offer an opportunity to develop *systems thinking* competences which, along with *creative problem solving* are key to supporting achievement of the SDGs (Blatti et al. 2019).

Several authors (Fitzpatrick, Byrne, and Gutiérrez Ortiz 2021; Quelhas et al. 2019; Mulder 2017) highlight the importance of *strategic competences* (such as innovation, creativity or entrepreneurship) for engineering graduates. Others argue for the integration of *intrapersonal competences* (Ortiz-Marcos et al. 2020; Pacis and VanWynsberghe 2020) but there is disagreement upon whether it is considered as a competence or an underlying disposition or mindset (Brundiers et al. 2021; Redman 2020). Lambrechts et al. (2013) outlined the importance of *emotional intelligence* (including transcultural understanding, empathy, solidarity and compassion) for successful sustainable development. More recently, the empirical findings of Ortiz-Marcos et al. (2020, 8) indicated *empathy and adaptability* among the most relevant competences, advising that engineers need to 'pay particular attention to their colleagues, are sensitive to the contextual conditions, and are able to change their behaviour and communication so as to adapt to the situation'. Quelhas et al. (2019), based on the result of their empirical study with experts in engineering education consider that *self-knowledge* and strategic vision are the most important competences, and conversely, *normative and anticipatory competences* are the least important competences for sustainable development.

Industry stakeholders call for *interpersonal competences,* such as communication, cooperation and teamwork (Ortiz-Marcos et al. 2020) and in a constantly changing world where knowledge becomes quickly obsolete, the development of *life-long learning* competences. Despite the importance of life-long learning, Trad (2019) found that amongst a set of seven sustainability competences, life-long learning and continuous reflection were the competences least integrated in engineering curricula.

Theoretical framework

Overall, the picture that emerges from the literature suggests that future engineers will require a wide range of sustainability competences to support the SDGs but there are various ways to categorise and prioritise these competences according to the researchers' views. More particularly in the field of engineering, there are relatively few studies which investigate the required competences needed of engineers to support the SDGs. To our knowledge, there are no prior studies in engineering education which investigate this question from different stakeholders' views at a European level. Considering this evidence, it seems that further research is needed to fill this gap and investigate this question from different viewpoints.

We were motivated, therefore, to answer three aspects of engineering competency requirements to support the SDGs:

- To identify a list of competences from key stakeholders
- To compare our outcomes with previous literature
- To identify differences between stakeholder views

The rationale behind the study was to collect the perceptions of three stakeholders of engineering education (academics, employers and students) and so we wished to generate conversation, including brainstorming sessions, discussion and possible debate on the topic. Hence, a qualitative research approach was employed (Creswell 2013) and focus groups were selected as the most appropriate method of inquiry. Outputs from the focus groups were coded (Corbin and Strauss 1990) to provide a comprehensive list of competence requirements.

We then opted to map our findings to the UNSECO (2017) framework complemented by the additional competences for sustainability identified in the literature. The UNESCO (2017) framework is specific to SDGs and so relevant to highlight dissonance in the findings of our study.

Finally, we wished to compare and contrast stakeholder views and so we compiled the competence lists for each stakeholder group and compared findings in order to highlight contrasts and to provide us with insights into differing perceptions.

Context of study and focus group set up

It is important at this point to provide overall context for the study, before focussing on the specific research questions presented in this paper. This study formed part of an EU project which included four academic partners, hence focus groups were carried out in the home countries for each academic partner, namely: France, Ireland, Finland and Denmark. More specific details on the findings which compare outcomes from each country are presented in Beagon et al. (2020), however, are not the focus of this particular paper.

The focus groups which formed this study are described in more detail in the next section and were organised in three parts. The first part focussed on the concept of Sustainable Development and participants were invited to brainstorm the themes associated with Sustainable Development. The purpose of this part was to give context to the differing conceptions of Sustainable Development by the participants. The second part of the focus group aimed to investigate the awareness of the SDGs in general and of specific SDGs in particular. Participants were initially asked to identify the SDGs they were aware of and then when presented with a summary of SDGs, were invited to rank and discuss the importance of each SDG, and in the case of students, how effectively each SDG was covered in their engineering programmes. A questionnaire was also used in this part to collect quantitative data. The findings from the first two parts of the focus group are published elsewhere (Beagon et al. 2021). The final part of the focus groups then turned to focus specifically on competences that engineers require to support the SDGs. It is important to note, therefore, that the research work published in this paper, immediately follows from a discussion of the concept of Sustainable Development and the SDGs in particular.

Twelve focus groups were organised with participants from key stakeholder groups of engineering education (academics, students and employers) in each of the four participating countries. Each focus group was organised independently of others (on different days and locations) and all discussions took place within one room. Students were recruited for the focus groups with the help of local groups of BEST (Board of European Students of Technology) or invited by email by the researcher. Academics were recruited in a similar way, through an invitational email and the participants included lecturers and researchers. Employers were contacted through industrial partners, the alumni network or through local professional organisations to ensure a broad reach of employer views.

There were no selection criteria applied to the focus group participants: all applicants who completed the ethical consent form were included. The research team realise that this may, therefore, include some participants who are experts in sustainability and some who are not, yet we see this as being a strength of the study as it offered diverse views on the topic. The team considered that each participant's view was relevant as students had an influence in the engagement in the curriculum, academics had perspectives on how important sustainability issues were and how they translated these values in the classroom and employers are responsible for real world application of sustainability values in their day-to-day work. The focus group participants also came from diverse discipline areas as shown in Tables 2 and 3.

As the research work involved human participants, ethical approval was required for the focus groups. Overall approval was granted by the TU Dublin Research Ethics and Integrity Committee and researchers in each country also gained ethical approval for focus groups within their respective universities. Focus group participants received written information about the objectives of the focus group study, confidentiality of data collected and the possibility of withdrawal. They provided written consent before the focus groups began.

Encouraging discussion from a diverse group of respondents was a key factor of the study design. It was also important for the participants that the focus group discussions would be carried out in a standardised way and that the outcomes could allow comparison between groups. To this end, a Focus Group Handbook was collaboratively agreed upon by all research parties and is available at www.astep2030.eu . Relevant extracts are included in Appendix A. The handbook was used to ensure that each country used a similar invitation e-mail, that similar questions were asked in each of the various focus groups and that the same questionnaires were used to collect quantitative data in relation to importance of SDGs. All project partners attended the first focus group as observers, to witness how the session would be facilitated so that they could replicate the focus group in their own country. It is recognised, however, that the fluid nature of a focus group makes complete standardisation difficult, but the detailed handbook and agreed reporting template facilitated comparison and synthesis and made the comparison exercise a less onerous task. The reporting template was initially created to report the Ireland Focus Groups findings and this template was then used by all parties. Extracts of the reporting template are included in Appendix B.

In specific relation to the research question addressed in this paper, participants were asked in small sub-groups (2–4 people depending on the number of participants) to brainstorm all the competences

Table 2. Number of focus group participants and level of expertise.

	Number of students and number of years of study	Number of academics and length of academic experience	Number of employers and length of experience working in industry
Ireland	7 1–5 years	9 1–20 years' experience	6 1–41 years' experience
France	9 3–5 years	7 2–20 years' experience	8 2–49 years' experience
Denmark	7 1–5 years	8 2–40 years' experience	6 20–35 years' experience
Finland	4 2–3 years	8 8–24 years' experience	7 15–37 years' experience

Table 3. Discipline details of focus group participants.

	Student disciplines	Academic disciplines	Employer disciplines
Ireland	Mechanical Civil Manufacturing General Engineering	Civil & Structural Electrical and Electronic Mechanical Building Engineering Mechanical and Design	Electrical Civil Structural Telecoms/IT
France	IT – Artificial Intelligence Naval Architecture Hydrography Oceanography Business Management	IT Mechanical Administration Quality Management & SD Foreign Languages Human & Social Sciences	Vehicle Architecture Hydrodynamic naval Pyrotechnic Electronics/Naval Arch Electronics/signal processing
Denmark	Computer Science Engineering Environmental Planning Export and Technology Urban Design Managerial Accounting	Environmental Planning Production Electronics Mathematics	Urban Development Agri-tech Technical Director CEE
Finland	Biotechnology Environmental Engineering Laboratory analytics Electric & Automation Engineering	Mechanical and Design ICT Chemical engineering Laboratory Science Environmental Engineering Automation	ICT Electrical Chemistry Physics

that engineers need to help achieve the sustainable development goals and these were recorded by each subgroup on small flipcharts. Although we did not define the term 'competences' for participants, we took that to include competences, skills, knowledge or attributes, in effect any term used by the focus group was accepted as relevant. The facilitator then asked each sub group to report their findings to the whole focus group whilst encouraging the groups to explain why they had chosen specific competences and what they understood by the terms used. This discussion facilitated interaction between groups and helped the researchers gain consensus on the meaning of the competences identified.

In total, there were 86 participants who engaged in focus groups as part of this study. The data collection took place in each country between March and July 2019. Focus group meetings lasted typically two hours and were undertaken in the native language of the participants in order to facilitate a deep discussion. All focus groups were digitally recorded and partially transcribed and only selected citations were translated into English. The data was then summarised and synthesised according to a standardised template and data treatment procedures including a coding exercise which is explained in more detail in the next section.

Data analysis and results

In relation to the qualitative nature of our study, it is important to recognise the influence of researchers' values and interpretations, the participants' interactions in the room or the recorded sessions on the behaviour of respondents. However, to ensure the validity of our study, we followed the recommendations and quality considerations of Kellam and Cirell (2018) in relation to conducting qualitative research in engineering education. These included, detailed descriptions of methods (context, data collection analysis and reduction), iteration of our theoretical framework to align with our methods and results and the use of two independent researchers. The steps taken in the analysis process are now described in detail along with the relevant findings for each research question.

The data analysis was carried out in four phases as indicated in Figure 1. The data comprised the written terms identified by each subgroup on the flipcharts, as the competences that engineers

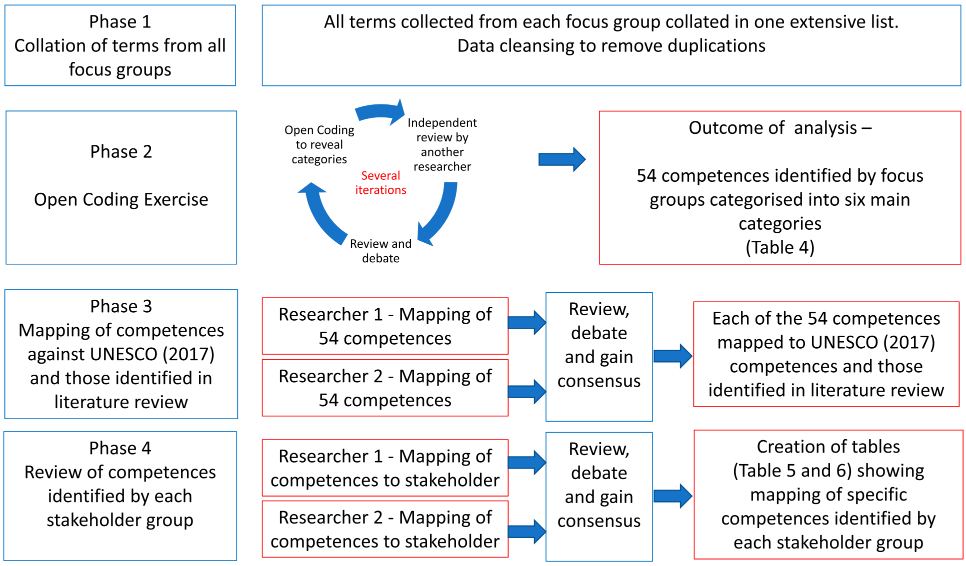

Figure 1. Process of data analysis.

require. The aim of the first phase, therefore, was to generate a complete list of terms which were gathered from all focus groups combined. This extensive list was then data cleansed to remove duplicates and similar terms in differing declensions (for example 'interpret' and 'interpreters' or 'critical thinking' and 'think critically' were combined). Similarly, terms which were not a competence were removed; such as 'realist', 'expertise'.

The purpose of the second phase was to develop a concise list of competences which reflected the terms generated in the first phase. We used the process of Open Coding (Corbin and Strauss 1990) in this phase. One researcher undertook an open coding exercise to create a list of sub categories emerging from the data. In open coding, each term was allocated to a particular sub category and then compared with others for similarities and differences. For example, 'Being able to plan' was coded to a sub category denoted as 'Planning', 'Good organisation' was categorised as 'Organisation' and with several iterations, this sub category became 'Organisation Skills'.

Once the initial coding exercise was completed by the first researcher, the extensive list was also provided to another researcher, who then, independently, allocated each term against the categories identified in the coding exercise. Both reviewers then met and discussed and debated the coding outcomes which after several iterations, resulted in a final list of 54 key competences (sub categories) which were determined to represent those raised in the focus groups.

Phase Two was completed when all of the 54 competences (sub categories) were then further coded into six main categories where 'conceptually similar ones are grouped together to form categories' (Corbin and Strauss 1990, 423). These six categories were determined to be; (1) Fundamental Technical Skills, (2) Application Skills, (3) Outward Facing – People Orientated Skills, (4) Inward Facing – Ways of Thinking, (5) World View and Character and (6) Ethical Orientation. These were further classified under the categories of Technical, Non-Technical and Attitudes. It is important to note at this point that the coding exercise was completed whilst bracketing any existing knowledge of competency frameworks, as we wished that the list of competences would emerge organically from this research work. We did not, therefore, at this point, attempt to categorise our findings into previous frameworks, but offer our findings as an alternative way of viewing the competence requirements needed.

Table 4. Focus group outcomes of competences needed for engineers to support the SDGs.

Technical		Non-technical		Attitudes	
Fundamental Technical Skills	Application Skills	Outward Facing – People Orientated Skills	Inward Facing – Ways of Thinking	World view	Character and Ethical Orientation
Mathematics Skills	Multidisciplinary Skills	Inter Cultural Skills	Critical Thinking	Global Awareness	Respect for others
Digital Skills	Problem Solving	Collaboration	Life cycle thinking	Social Responsibility	Open mindedness
Economic Skills	Design Skills	Leadership	Holistic Thinking	Challenging the status quo	Agility
Research Skills	Interpretation Skills	Conflict Management	Systems thinking	Sustainability Awareness	Adaptability
Technical Skills	Conceptual understanding	Negotiation	Creativity	Environmental Awareness	Curiosity
	Resources optimisation	Communication[a]	Analytical Thinking	General Knowledge	Empathy
	Innovation	Foreign Languages	Stress Management	Lifelong Learning	Emotional Intelligence
	Entrepreneurship	Listening	Time Management		Perseverance/Grit
	Decision Making Skills	Respecting Diversity	Self-Reflection		Ethical Conscience
	Learning to Learn	Teamwork	Multi-perspective thinking		Personal engagement/agency
	Project Management	Inter Cultural Skills			
	Organisation Skills				
	Problematisation				

[a]Communication was identified as a competence which included communication, foreign languages and listening skills.

Table 5. Focus group outcomes of competences needed for engineers to support the SDGs indicating level of agreement between stakeholder groups of engineering education (mapping against UNESCO 2017).

		Students	Academics	Employers
Key competencies for Sustainability relevant to all SDGs (UNESCO, 2017)				
Systems thinking competency				
	Analytical Thinking	√	√	√
	Holistic Thinking	√	√	√
	Global Awareness	√	√	
	General Knowledge	√		√
	Systems Thinking		√	√
	Life cycle Thinking	√		
Anticipatory competency				
		None identified in this study		
Normative competency				
	Ethical Conscience	√	√	√
	Social Responsibility	√	√	√
	Sustainability Awareness	√	√	√
	Environmental Awareness	√		√
Strategic competency				
	Innovation	√	√	√
	Creativity	√	√	√
	Project Management	√	√	√
	Decision Making Skills	√	√	
	Design Skills	√		√
	Organisation Skills	√		
	Entrepreneurship		√	
	Resources optimisation		√	
	Conceptual understanding		√	
Collaboration Competency				
	Communication	√	√	√
	Collaboration	√	√	√
	Teamwork	√	√	√
	Personal engagement & agency	√	√	√
	Listening Skills	√	√	
	Emotional Intelligence	√	√	
	Respect for others	√		√
	Inter-Cultural Skills		√	√
	Foreign Languages		√	√
	Respecting Diversity		√	√
	Leadership	√		
	Conflict Management		√	
	Negotiation		√	
	Empathy		√	
Critical thinking Competency				
	Critical Thinking	√	√	√
	Open mindedness	√	√	√
	Curiosity		√	√
	Self-Reflection		√	
	Challenging the status quo			√
Self Awareness Competency				
	Perseverance/Grit	√	√	
	Adaptability	√		√
	Agility	√		√
	Time Management	√		
	Stress Management	√		
Integrated Problem Solving Competency				
	Problem Solving	√	√	√
	Research Skills	√	√	
	Problematisation		√	
	Interpretation Skills			√

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The outcomes of Phase Two answers the first research question related to the competences that key stakeholders perceive are necessary for engineers to support the SDGs. A total of 54 competences were identified by focus group participants and they are presented in Table 4 coded within six main categories.

Table 6. Focus group outcomes of competences needed for engineers to support the SDGs indicating level of agreement between stakeholder groups of engineering education (mapping against additional competences identified in literature, but not included in UNESCO 2017).

		Students	Academics	Employers
Interdisciplinary work				
	Multidisciplinary Skills[1]	√	√	√
Continuous Learning				
	Learning to Learn		√	√
	Lifelong Learning		√	√
Implementation competence				
		None identified in this study		
Transdisciplinarity				
		None identified in this study		
Fundamental Disciplinary competences				
	Technical Skills	√	√	√
	Economic Skills	√	√	√
	Digital Skills	√		√
	Mathematics Skills			√

Green denotes competences where all three stakeholder groups have identified this as a key requirement, Yellow denotes situations were two stakeholder groups identified a competence and Blue indicates competences which were raised by only one stakeholder group.

The third phase of analysis aimed to map the 54 competences uncovered in this study to previous literature. The outputs of this phase answer the second research question 'How do the competences identified in this study context compare to the "Key competencies for sustainability" published in UNESCO (2017) and more recent literature?'

As a reminder to the reader, the literature review considered the seminal Wiek, Withycombe, and Redman (2011)'s publication for Key Competencies [*sic*] in Sustainable Development and we complemented this with competences identified in more recent literature (Table 1). It is important to note, however, that the literature review covered sustainable development literature in general, but our study specifically focussed on the SDGs. As there were limited studies in the literature on competences for the SDGs we felt it was important to review more widely in the literature review. However, as part of the mapping exercise, we determined that it was both appropriate to compare our findings with the UNESCO (2017) framework which is relevant specifically to the SDGs, but also to the more widely identified competences relevant to Sustainable Development.

Again, in this phase, the initial mapping exercise was completed by the first researcher and was then completed independently by a second person in the team. Both researchers then met and discussed and debated the mapping exercise until agreement was reached.

We have presented the results in Tables 5 and 6 which show the outcome of the mapping exercise and the level of agreement between stakeholder groups. Table 5 outlines the competences identified by UNESCO (2017) and Table 6, the additional competences identified in the literature review (from Table 1, which are not included in UNESCO (2017)).

The final phase of analysis sought to compare stakeholder views and so as indicated in Tables 5 and 6, the competences were mapped by each stakeholder group to show which stakeholder group had noted each competence. The final part of this section outlines the findings of this comparative exercise along with relevant quotes from focus group participants.

Systems thinking competence

Analytical thinking and holistic thinking were mentioned by all stakeholder groups but particularly underlined by academic participants in relation to technical and application skills. Holistic thinking was defined 'as the capacity to make a good synthesis … and see the whole picture' (FR-A).[5] *Global awareness* and *general knowledge* were also acknowledged as important.

> When we train our students, they do what we say to do. They have no risk and responsibility. However, when they are in a real working situation, they have a responsibility and they have to be able to justify their actions and apply global thinking. (IRL-A)

Furthermore, Finnish Academics felt it was important that students have an 'ability to perceive the worldwide situation, not only from the engineers' perspective, but also from other viewpoints' (FL-A). The view is that one of the principal missions of University is to teach these ways of thinking. In the words of one employer:

> When I went to college, it didn't teach me to be the engineer I became, but it did teach me how to think, how to think logically. I think it's important that universities need to continue to do that through teaching technical and analytical subjects. (IRL-E)

Normative competence

<u>*Social Responsibility*</u> and <u>*sustainability awareness*</u> were perceived by all three groups as necessary for future engineers. Academic participants considered that engineering schools have an important responsibility to develop these competences in students. 'If we leave out the technical things, we are just trying to make good citizens. That's the role of the Universities' (IRL-A). The reference to 'good citizens' is taken to mean an acknowledgement of social responsibility. As an academic further explained:

> The new graduates I deal with now, they have much more social conscience around the environment. They are far more engaged, far more aware of what's going on and tend to question stuff a lot more. So I think through education, we are building that desire to save the planet. (IRL-A)

Students viewed it more specifically as the 'Ability and willingness to develop environmentally friendly products' and 'Knowledge about how to calculate CO_2 footprints of materials and products' (FL-S). Both academics and employers noted that the younger generation are more concerned than ever about environmental concerns. However, academics felt there were barriers to teaching students these competences which included a lack of expertise from engineering academics on some of the broader social goals and a lack of space in the curriculum. Similarly, students expressed that 'In engineering schools, there is a lack of education about sustainable development awareness like eco-responsibility, use of recycling material and renewable energy … it could be integrated in engineering training, as an example in the mechanical design courses … ' (FR-S). As one Danish employer noted, 'engineers must have an equal understanding of the focus on the economic, social and ecological conditions. The engineer must be able to see all; a tunnel construction as well as a policy decision and an infrastructure context' (DK-E).

<u>*Ethical conscience*</u>, was also closely related to the concept of social responsibility and sustainability awareness. As one employer put it 'it's easy to make a choice when there is no cost. But when the choice becomes more difficult is when it costs more to do the right thing and that's when we run into difficulty' (IRL-E).

Strategic competence

<u>*Innovation, creativity*</u> and <u>*project management*</u> were considered as critical competences for engineers by all stakeholder groups. According to employers 'innovation capacity' and 'the application of diverse methods to innovate' are key requisites for the survival of businesses and industrial organisations, whilst recognising that 'the framework for innovation must be present' (DK-E). As one French employer stated: 'My company, like all big companies, puts in a lot of effort to innovate […] because a company cannot survive today if it does not make a profit' (FR-E). However, several employers also emphasised the societal nature of innovation as 'my company is working on improving life in the cities, so that they become more human, resilient and sustainable' (FR-E) or 'we try to innovate with innovations that have a positive impact on sustainable development' (FR-E). Creativity

was viewed as a basic engineering skill strongly related to innovation capacity. It was highlighted specifically by employers who perceived creativity as determining their innovation activities. Academic participants mentioned the necessity of creativity 'in the case of a breakthrough in innovation […] for producing new products' (FR-A). Student participants proposed that the development of creativity skills should be emphasised more in engineering schools. Academics recognised the importance of giving students an opportunity to practice project management skills in group projects, 'without applying project management in teamwork scenarios, students fall behind and miss out on key parts of the knowledge to be gained' (DK-A).

Design skills were mentioned by students and employers in tandem with innovation capacity as specific skills that could be applied to achieve the SDGs, yet design skills were not perceived as important by academics. *Decision making* skills were highlighted by student and academic participants, in particular, 'being aware of the consequence of our actions and decisions on society […] with a systematic analysis of the environmental and social impact … ' (FR-S). One academic viewed decision making as the ability 'to be able to make decisions and take risks and realise our responsibilities … some students have difficulty in doing this. However, for the SDGs it is fundamental' (FR-A). Academics also recognised the opportunity they have to help students develop these skills. 'Students make decisions in every assessment they do, but they are not aware of it' (IRL-A). Finally, academics also recognised that *entrepreneurship, resource optimisation* and *conceptual understanding* competences were key to solving the SDGs, but none of these competences were acknowledged by students or employers.

Interpersonal competence

Interpersonal competence is interpreted as competences associated with engaging with people, on a general level, regardless of their discipline. *Communication, collaboration and teamwork skills* were the most common competences that were recurrently identified in all focus groups. 'Engineers need to be able to "communicate" the answer too' (IRL-E). Although there was a shared agreement about the importance of good *communication skills*, there were differences identified between foreign languages and listening skills. First, *foreign languages* were not mentioned at all by student participants but were highlighted by both academics and employers. In Ireland, a brief acknowledgement came from academics in the form of 'the limitations of your own language' (IRL-A), but language skills were not mentioned specifically by any of the groups in Ireland. *Listening skills* were mentioned by students and academic participants as a basic competence needed to work well collaboratively. 'Negotiation skills, listening and reciprocity' (FL-A). Despite the recurrent view of the importance of communication skills, there still appears to be a gap between graduate skills and employer expectations. One employer stated 'there needs to be a focus on communication skills, I interview a lot of engineers and some of them come in lacking in those skills, particularly compared to business graduates' (IRL-E).

The importance of being able to collaborate was identified in all stakeholder focus groups. For employers, *collaboration skills* were closely related to the strength of international partnerships in an intercultural environment: 'Partnership building and collaboration … that means to be able to work together with people who do not have the same culture. When working in a team, if everyone has good ideas, we get a better result' (FR-E). Academics felt that existing graduates do already have skills in collaboration and this is important for success in industry: 'graduates are bringing in interdisciplinary collaboration skills – collaboration across disciplines and boundaries – being able to communicate with customers and stakeholders about their needs and concerns' (DK-A). Both student and academic participants considered collaboration skills as particularly valuable and are taught well in engineering schools through the use of project work.

All stakeholder groups perceived *teamwork* as a fundamental skill for effective and efficient collaborative work. As an Irish employer noted: 'engineers will also need to manage diverse project teams, there are no longer only engineers on teams. […]. They now include environmentalists, economists, institutional capacity builders, all kinds of people' (IRL-E). According to an academic participant, it is also particularly important to 'promote the quality of work together … give our students the tools and methods to collaborate better … .and make them able to transfer this collaborative work elsewhere … ' (FR-A). Correspondingly, employers thought 'multidisciplinary teamwork is needed, it's the way we work, but this is lacking in Universities' (IRL-E). Linking the idea of working on projects, and *inter-cultural skills*, an employer highlighted the importance of 'project management with multicultural partners and being able to understand each other […] as multiculturality goes together with partnership building' (FR-E).

Other skills, such as *respect for others, respecting diversity, empathy or emotional intelligence,* were considered as much needed but not sufficiently promoted in engineering curricula. Academics asked

> When do they start learning these things? Do they start in primary? What's the status of that individual before they come to University? We can't just start in 3rd level when they arrive and say 'Right, let's start with emotional intelligence'. Empathy is developed through awareness, we need to expose them to opportunities where they can empathise with people. Therefore, we should teach behavioural sciences. (IRL-A)

However, there is evidence that employers also see the value in supporting these goals. When asked what is needed, one French employer stated 'Education and gender balance … we are trying to achieve gender equality and diversity' (FR-E). One specific requirement was to have a 'positive attitude towards work' (FL-E) whilst the importance of doing something properly was also highlighted 'They must be able to stand on a strong base of professionalism: the houses must be able to stand and the bridges should not collapse' (DK-E).

Interdisciplinary work

Interdisciplinary competences are interpreted as competences associated with engaging with people of different disciplines, therefore, not engaging with people at a general level, but placing focus on the disciplinary differences. *Multi-disciplinarity* was also perceived by all stakeholders of engineering education as a necessary competence in a world with growing complexity. However, as one academic participant noted: 'Multidisciplinary work is important, but students must have basic technical skills first before they can contribute to multidisciplinary team projects' (IRL-A). For students, multi-disciplinarity is a central skill as it 'applies to many things … it's in the middle' (FR-S). They considered that the integration of more multidisciplinary courses into engineering programmes would be beneficial. Employers noted that the silo structure in some universities does not help 'Universities have separate faculties and that's a challenge. Someone needs to take that facilitators role to ensure multidisciplinary working takes place' (IRL-E). Employers also noted that multidisciplinary skills are viewed not as having a breadth of knowledge in different disciplines but the capacity to make links between disciplines and apply this knowledge. As one employer stated: 'Each student has to have his/her own field of expertise. Not all people can be generalists' but equally a student 'has to understand how this his/her special expertise is connected to others' (FL-E).

Critical thinking

Whilst all stakeholder groups acknowledged that *critical thinking* was a key competence for engineers, students in particular noted:

> Especially in the world we live in now, where all the information that you need to have off the top of your head, you probably can get on the internet. Which is why you need critical thinking skills even more because there is so much more information available, you need to be able to tell what is reliable and what isn't. (IRL-S)

This view is shared with academics who supported 'criticism of sources, criticism of media, criticism of prevailing practices' (FL-A). However, with regard to inclusion in the curriculum, students noted 'Critical thinking should be integrated into all of our courses … it is not a separate subject in itself' (FR-S). All stakeholder groups also acknowledged the importance of having an *open mind*.

Challenging the status quo was a competence identified by employers, but not by students nor academics. This is described as to 'think outside the box – dare to challenge the reverse! Young newly qualified engineers must dare to challenge older employees' (DK-E).

Life long learning

It is interesting that the importance of *learning to learn* was outlined by academics and employers but not by students, for whom it will be critical for their professional life in the future. '*Lifelong learning* … and to learn how to learn are important … Create new training courses with a lifelong learning perspective … ' was one employer's focus of interest. 'Lifelong learning for employees is more in the company's interest than for just the individual. … we have autonomous training modules and our training courses are integrated into our professional practices' (FR-E). According to an academic participant: 'Our engineering students need more exposure to this [SDGs]. A lot of these goals relate to lifelong learning, not necessarily technical topics and we should bring in engineers or non-engineers to teach them about these' (IRL-A).

Intrapersonal competences

Students identified more intrapersonal competences than employers or academics, and also highlighted *time management* and *stress management*, neither of which were identified by the other stakeholders. There was further dissonance between stakeholder groups on the importance of *perseverance/grit, adaptability and agility.* However, one employer was clear on what is required:

> Technology will be neutral, I look at an engineer's capacity, their intellect, the way they think. Can they solve problems? Do they have a good attitude? They will learn technologies over time. The task for Universities is to train engineers who are flexible, agile, can adapt over time, and have good rigour. (IRL-E)

Integrated problem solving

In the words of a student participant: '*problem solving* is really the basis of everything we need to do as an engineer' (IRL-S). Academic participants spoke more precisely about 'technical problem solving' (FR-A) as one of the key missions of an engineer. They also highlighted the importance of being cognisant of supporting the students learning process. 'The quality of the problem solving depends on the quality of the initial analyses into the problem and its context. This is an analytical process in which our students train consistently and repeatedly for five years' (DK-A). Whilst problem solving was recognised by all stakeholder groups, conversely, *research skills* were identified as important by academics and students but not by employers. For students, research skills were only needed in specific cases which were related to solving the problem. As expressed hesitantly by one student: 'Research skills possibly. I'm only saying possibly because there's always room for improvement but if you have the solution it can just be a matter of implementing it' (IRL-S).

Fundamental disciplinary competences

Technical skills were considered by all stakeholder groups as an essential requirement to work towards the SDGs, the core of engineering curricula. However, there was a common understanding that fundamental technical skills have to be complemented with non-technical or transversal skills. As one academic participant stated: 'hard-core, solid technical skills are required – however, if engineers have technical skills only that is clearly inadequate' (DK-A). 'Technical skills are really important and we shouldn't compromise those' (IRL-E). 'Basic studies of a student's own field are important. She/he has to know the key principles' (FL-E). There was unanimity between the three groups that these skills are generally well covered in universities. From the point of view of employers: 'The technical skills and competencies … these are well taught in engineering schools, this is their principal mission … ' (FR-E). 'Graduates need to be technology savvy but we assume we will get that anyway' (IRL-E). However, one employer also warned that the technical skills currently taught do not always keep pace with progress. 'Graduates need updated technical skills to keep up with new technologies. Academic and training institutions are falling behind. They are not covering what we are doing in industry with new technologies' (IRL-E).

In addition to technical skills, *economic skills* were also identified by all stakeholder groups. As one student stated 'to live in an economic world, we must have economic skills, to enhance an economic culture that allows us to perceive the world today … especially for innovation' (FR-S). These economic skills are also relatively well covered in engineering curricula and viewed by academic stakeholders as complementary skills:

> I brought in a guest lecturer, a lawyer to talk about tax and how companies can avail of tax initiatives with regard to innovation. The students were blown away by it. This was a whole new perspective that they hadn't thought about before. (IRL-A)

Digital skills were mentioned by students and employers in the context of 'digital flair – digital qualifications' and as 'IT tools for modelling' (DK-A). There was a general agreement that young students' intuitive approach to digital tools surpass those of the older generation. 'Digital skills – the students (young people) are far ahead! The young can do more, far more than us older folk. They have a very intuitive dedication to technology' (DK-E). Digital tools for specific engineering tasks are also expected to be included in technical programs, and are seen as 'being embedded within the technical skills related to a profession' (DK-A).

Specific ability in *mathematics* was identified only by employers, but not identified as necessary to support the SDGs by engineering students or engineering academics.

Discussion

Our findings indicate relatively good agreement between students, academics and employer stakeholders concerning the normative, strategic, system, interpersonal, fundamental disciplinary, interdisciplinary work, critical thinking and integrated problem solving competences. However, there is a divergence between stakeholders' perceptions of intrapersonal and continuous learning competences. Finally, anticipatory competence was not identified by the participants in this study.

Based on the findings of this study, four important issues were identified which can provide new insights and an opportunity for further investigation. The first and most surprising issue is the relative absence of anticipatory competence, which was not directly perceived by the participants of this study. However, we attest that this competence is not entirely absent as similar terms were indicated inherently in other competences (e.g.: life-cycle thinking, lifelong learning or time management). As noted earlier, anticipatory competence is one of the key competences identified by UNESCO (2017). Future thinking competences, such as anticipating and estimating consequences, dealing with uncertainty and future changes or envisioning possible futures are considered by numerous authors as critical sustainability competences (Heiskanen, Thidell, and Rodhe 2016; Rieckmann 2018; Quelhas et al. 2019; Brundiers et al. 2021; Redman, Wiek, and Barth 2021). Several authors (Quelhas et al. 2019; Staniškis and Katiliūtė 2016; Wangel et al. 2013) also consider that visualising future scenarios by taking both a broad and long view from different perspectives is particularly relevant for engineering graduates. However, we must highlight that there are contradictory results concerning the importance of anticipatory competence[6] based on the perception of experts and industry stakeholders (Demssie et al. 2019; Quelhas et al. 2019; Quendler and Lamb 2016; Rieckmann 2012). Despite these contradictions, several authors (Anholon et al. 2020; Rosén et al. 2019; Ojala 2017) propose that there is an opportunity to better integrate anticipatory competence development in the engineering education curriculum as there is a growing need for future-oriented graduate engineers (UNESCO 2021). The findings of this study suggest that none of the key stakeholders in engineering education acknowledged that this competence is necessary and hence, there is work to do both in extending the awareness of and teaching methods to expose students to opportunities to develop anticipatory competence.

The second issue is the importance of normative competence for graduate engineers with the unanimity of all stakeholders confirming the results of Quendler and Lamb (2016). As stated by academic and employer stakeholders, recent engineering graduates have stronger environmental and social motivations to contribute to society (Haase 2014; Fitzpatrick, Byrne, and Gutiérrez Ortiz 2021) whilst simultaneously considering economic, environmental and social dimensions of sustainability. However, as noted by academic stakeholders in this study, there are barriers at the individual, disciplinary and institutional level (Holgaard et al. 2016) such as a lack of competence of engineering academics to teach particular topics or a crowded engineering curriculum (Leifler and Dahlin 2020). These barriers make it difficult to shift the educational paradigm by emphasising values and commitment to sustainability (Kolmos, Hadgraft, and Holgaard 2016). It is important, therefore, that engineering educators are sufficiently trained and that they also acknowledge and integrate normative competence, within technical modules, to avoid additional pressure on the already overcrowded curriculum.

The third issue is the strong acknowledgement of interpersonal competence, indicating that these competences are highly relevant in the context of advancing a sustainable future (Konrad, Wiek, and Barth 2020). The four aspects identified by all stakeholders of engineering education (communication, teamwork, project management, personal engagement and agency) are in line with the domain of professional skills identified by Brundiers and Wiek (2017). These findings confirm the results of Ortiz-Marcos et al.'s (2020) investigation into the perception of academic and industrial stakeholders as discussed in the literature review. Interpersonal competences such as communication, teamwork, resilience and agility are viewed as critical competences and will be valued and recognised in engineering (UNESCO 2021). Even if these competences are perceived by students as well taught through project work (Segalàs and Sánchez Carracedo 2020) there is an existing gap between industry requirements and students' actual interpersonal competences (Ortiz-Marcos et al. 2020). This finding makes the case that there needs to be more emphasis and explicit assessment of interpersonal competences in order to reduce this gap, rather than relying on gaining these competences implicitly through project work.

Finally, the fourth interesting issue is that continuous learning was identified as a highly relevant sustainability competence by academics and employers alone, not by students. This finding broadly supports the work of Demssie et al. (2019) where the majority of experts from academia (68.8%) and industry (76.5%) found continuous learning as a relevant or very relevant sustainability competence. As Guerra (2017) stated, continuous learning is an essential professional competence for engineering students to become independent and autonomous learners. It prepares them to be flexible and adaptable for their future as a professional engineer. A broader vision, where graduate students are involved in a continuing learning process at their workplace aligns well with the concept of EESD, as it is considered a life-long process (Quendler and Lamb 2016). The concept of lifelong learning and professional development for students is, therefore, yet another crucial aspect which needs to be better integrated in the engineering curriculum. Personal development planning and regular review of progress, such as keeping an e-portfolio may be a solution to this issue, which focuses the student on the future without adding yet another module to a curriculum.

Turning to the comparison of competences by stakeholder groups, employers request a focus on mathematics skills and interpretation skills, whilst urging academia to help students 'challenge the status quo'. Academics focus on the need for application skills such as conceptual understanding, resources optimisation and entrepreneurship, or people orientated competences such as conflict management and negotiation, competences not identified by employers or students. Finally, students see value in developing competences in organisation, leadership, life cycle thinking, stress and time management, competences not identified as important by either employers or academics.

Looking more closely, we observed differing perceptions in relation to intrapersonal competence. Surprisingly students identified a relatively wide range of aspects in this category (compared to the limited perception of academic and employer stakeholders) indicating a personal focus on self-care, interactions and well-being at work, similar to the findings of (Brundiers and Wiek 2017). We attest, therefore, that academics and employers may have lessons to learn from students, acknowledging the importance of personal mental health and well-being, aligning with the focus of SDG 3 (Good Health and Well Being).

Concerning system and strategic competences, as expected, our findings confirmed their importance by underlining the role of the University to develop these competences (UNESCO 2021). Furthermore, critical thinking and problem solving were also identified, but with an emphasis on traditional technical problem-solving and not integrated problem solving, which is highlighted in particular by Brundiers et al. (2021).

In the category of fundamental disciplinary competences, technical and economic competences were identified by all stakeholders. It is widely recognised that graduate engineering students have good technological knowledge in their disciplines (Fitzpatrick, Byrne, and Gutiérrez Ortiz 2021; Quendler and Lamb 2016) in addition to relatively good economic competences. However, academics appear not to recognise the importance of digital skills, suggesting that academic staff need to recognise and perhaps be trained in cutting edge digital skills.

Overall, with the exception of intrapersonal and continuous learning competences, there is relatively good agreement between stakeholders' perceptions and our findings correlate with previous literature. The general agreement on stakeholder views is encouraging, and could facilitate future collaboration between all engineering education stakeholders for a better deployment of the UN 2030 Agenda (Romero et al. 2020).

Conclusion

This study investigated the differing perceptions of the required competences for engineers in order to support the achievement of the SDGs. The motivation for this investigation was to identify competences, and highlight gaps so that we could provide proposals for engineering curricula to better prepare engineers to contribute to the SDGs.

Based on the findings of this study, seven out of eight of the UNESCO (2017) framework competences were identified by the twelve focus groups which contributed to this study. Additional competences such as continuous learning, interdisciplinary work or fundamental disciplinary competences were also recognised. The findings confirm the strong emphasis on normative, strategic and system thinking competences in engineering. The most obvious finding to emerge from the study is the importance of interpersonal competences for engineering graduates, perceived as critical by all stakeholder groups of engineering education. However, the lack of acknowledgement of anticipatory competence raises numerous questions, as it contradicts the future oriented perspective of sustainable development.

Our results demonstrate to engineering educators the growing importance of engineering education in realising the UN 2030 Agenda (Romero et al. 2020). As highlighted previously, key stakeholders of engineering education (Employers, Academics and Students) have relatively similar perceptions of the required competences to support the SDGs and overall an agreement that there needs to be better integration of them into the engineering curriculum. However, we have to recognise that it is challenging to implement EESD in an overcrowded engineering curriculum with numerous existing obstacles (Holgaard et al. 2016). As a result, we encourage educators to think about this task strategically, and to consider integrating them alongside disciplinary, general or other professional competences (Redman 2020) whilst using active learning approaches as an appropriate pedagogy (Casanovas, Ruíz-Munzón, and Buil-Fabregá 2021). We also attest the importance of applying a holistic approach in this transition, considering an integration of strategy

(Kolmos, Hadgraft, and Holgaard 2016; Rosén et al. 2019), pedagogical approach (Quelhas et al. 2019; Tejedor, Martí, and Segalas 2019a; Evans 2019; Lozano et al. 2017; Guerra 2017), learning outcomes (UNESCO 2017; Kioupi and Voulvoulis 2019; Segalàs and Sánchez Carracedo 2020) and competence development (Ortiz-Marcos et al. 2020).

The main limitation of this study is that we have investigated only three groups of stakeholders of engineering education but recognise that others exist such as national accreditation bodies, non-governmental organisations, professional engineering bodies and social communities. Focus group participants represented various engineering fields but the study did not investigate stakeholder views differentiated by personal characteristics (such as discipline, age, gender, professional experience, etc.). We also included engineering employers who are responsible for recruitment of graduate engineering students, but did not consider variation in relation to societal or industrial sectors in each country. Furthermore, the study was limited to four European countries situated mainly in the North and West of Europe and hence is not representative of Europe as a whole. It is also important to recognise the limitation as a result of the use of diverse languages in the four countries and consequently the interpretation of competences by the participants.

Future studies could validate the proposed sustainability competences for graduate engineers on a larger scale and could assess the transferability of our findings to other European countries or in other contexts (US, Australia or emerging countries). It would also be interesting to replicate our study in many engineering fields and to explore the differences between specific engineering disciplines. In addition, it would be worthwhile comparing the findings to other professional domains outside of engineering. This research outcome has also raised new research questions, such as the meaning of future thinking for engineers, the significance of inter – and intrapersonal competences and students' perception of continuous learning, all of which could support new research work.

Notes

1. https://en.unesco.org/themes/education-sustainable-development/what-is-esd/SD.
2. These selected studies on key competences in sustainability are founded on evidence-based studies and/or comprehensive literature reviews.
3. The CDIO Syllabus proposes general objectives for engineering students in the CDIO context.
4. We consider multidisciplinary as the juxtaposition, interdisciplinarity as the interaction and transdisiplinarity as the integration of different disciplines during collaboration (Choi and Pak 2006).
5. The citations have been coded as: France (FR), Denmark (DK), Finland (FL), Ireland (IRL) and stakeholder groups as Academics (-A), Employers (-E) and Students (-S).
6. According to the results of Rieckmann (2012), anticipatory thinking was perceived by experts from academia as the second most important competence for sustainability (from a list of nineteen competences). For Demssie et al. (2019) the third (experts from academia) and the fifth (experts from the industry) most important competence out of a list of seven. In the Quelhas et al. (2019) study, anticipatory thinking was viewed by experts from academia as the least important competence (from a typology containing eight competences).
7. We define multidisciplinary skills as the ability to work with people from multiple disciplines.

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Notes on contributors

Dr Una Beagon is Assistant Head of School of the School of Civil & Structural Engineering at the Technological University, Dublin and a Fellow of the Institution of Structural Engineers. Her research in Engineering Education centres around using pedagogical initiatives to improve professional skills in engineering students, shaped by her previous industry experience as a consulting engineer in Ireland and abroad. Her interests also include phenomenography as a research method, problem-based learning and the first-year experience.

Dr Klara Kovesi is currently an Associate Professor of Management at ENSTA Bretagne where she is in charge of teaching management, marketing and entrepreneurship. Her main research interests are in the field of engineering education include; entrepreneurship education, interdisciplinary teaching and learning, and skills and competencies development for engineers.

Dr Brad Tabas is Associate Professor of English and Social Sciences at ENSTA Bretagne. His recent research has two interrelated focal points. The first involves developing and theorizing pedagogical innovations which foster a sense of social and environmental responsibility in STEM students. His second involves the application of STS tools to the analysis of the cultural politics of anticipated futures, with a particular focus on critically analyzing the fantastic justifications for perpetuating unsustainable forms of life.

Dr Bente Nørgaard is Senior Lecturer at the UNESCO Centre for Problem Based Learning in Engineering Science and Sustainability, Department of Planning at Aalborg University, Denmark. Bente's research field is Continuing Engineering Education (CEE) primarily with a focus on small and medium sized enterprises (SME's). She holds a Ph.D. which was entitled "Implementing Problem Based Learning as an approach for Continuing Engineering Education". Bente has an extensive national and international network. This has been built through experiences from several national and international research and developing projects, most recently with a broad perspective on cross-collaboration between enterprises and universities. Bente is a council member of 'The International Association for Continuing Engineering Education' (IACEE) and she chairs SEFI's Working Group on Continuing Engineering Education and Lifelong Learning.

Riitta Lehtinen works as a principal lecturer in Metropolia University of Applied Sciences in Helsinki. She has over 17 years' experience as a head of engineering degree programs and as a director of Division of Industry and Built Environment (consisting of 16 engineering degree programs). Her core competencies in addition to engineering education pedagogy, management and leadership are food technology and hygiene in food production chains and her current interests are in circular economy and sustainable development. Since 2016 Riitta has been leading different circular economy -projects, the aim of which is to promote students' understanding of the change from linear to circular economy.

Professor Brian Bowe is the Head of Academic Affairs and Assistant Registrar at Technological University Dublin -City Campus. In 2000 he formed the Physics Education Research Group and in 2008 he established the Engineering Education Research Group. In September 2013, he merged these groups and created a new research group to encompass all STEM education research activities: CREATE. His education research interests include examining students' approaches to learning within group-based project-driven pedagogies, epistemological development, progression, conceptual understanding and pedagogical evaluations.

Dr Christiane Gillet is an Associate Professor in Management at ENSTA Bretagne and in charge of the co-operative multidisciplinary engineering program . Her main research interests include: crisis management, leadership education, project based interdisciplinary learning and teaching and the development of innovative pedagogical programmes in management for engineers.

Claus Monrad Spliid is teaching associate professor at the Aalborg Centre for Problem-Based Learning in Engineering Science and Sustainability, Department of Planning, Aalborg University, Denmark. He is trained in agriculture (MSc), education (MEd) and narrative communication, and he has extensive experience in facilitation (technical, methodological, pedagogical). Claus has been working with learner-led and learner-centered education in professional settings as well as institutional settings since 1984. Over the years he has been involved in faculty development and capacity building for colleges, universities and institutions world wide.

ORCID

Una Beagon http://orcid.org/0000-0001-6789-7009
Brian Bowe http://orcid.org/0000-0002-4907-1913

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