A-STEP 2030

ACTIVITY 1: TASK 1
LITERATURE REVIEW

Report on the future role of engineers in society and the skills and competences engineering will require

Written by	Reviewed by
Brad Tabas Una Beagon Klara Kövesi	Brian Bowe Eddie Conlon Richard Manton Bente Nørgaard Damien Owens

AGENCE ERASMUS+ FRANCE - EDUCATION & FORMATION

Erasmus+

FRAMEWORK OF THE LITERATURE REVIEW

This literature review outlines the current state of the art knowledge in relation to the influence of diversity, attractiveness of the engineering profession and the skills and competencies required of engineers to achieve the SDGs. We aim to answer the overall research question:

> How do engineering educators develop new learning and teaching approaches (methods) that will attract a diverse group of students (and mature learners) whilst achieving the SDGs in 2030?

The main objective of the A-STEP 2030 project is to create an attractive and fascinating learning environment to encourage young people with diverse backgrounds to engage in engineering studies and the profession as a whole. The aim of this project is threefold:

• In Activity 1, we would like to determine the future roles and skills requirements of engineers to enhance the sustainable development of our society. For this reason, we ask the questions:

- What are the skills and competencies that engineers need to resolve the SDGs?
- What are the future professional roles of engineers in relation to the global issues facing our society?

• In Activity 2; we investigate the intrinsic values and motivations of young people, students and adult learners in order to determine how this influences their future career choices and to use this knowledge to make a career in engineering more attractive to all. We propose several research questions:

- What are their preferences in making their future career choices?
- What are the values and motivations influencing their decisions?
- How do they perceive the engineering profession and their ideal future employer?
- Where are the gaps between their expectations and the needs of the future engineering profession?

• In Activity 3, our objective is to develop new and innovative teaching and learning practices to encourage our diverse population to engage in engineering studies and the profession as a whole. To do this, we examine:

- Is there a relationship between sustainable development and diversity?
- How to encourage a diverse population to engage in engineering studies and the profession? How to optimise diversity?

For our literature review study, we applied a traditional literature review method by collecting articles related to the following five topics in line with our 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.

We searched relatively recent (in the last 15 years) peer reviewed scientific journal articles, conference papers, scientific books and reports. For our search, we used available scientific journal databases (e.g.: Science Direct, ERIC), library catalogues and subject specific websites (e.g.: EE publications on the SEFI website).

Contents

Introduction

What will the engineer of tomorrow look like? How will this engineer go about his or her work? How will they understand their relationship to society? What skills will they need, and what world will they create?

The following pages modestly aim to shed some light on these questions. Today is a crucial period in the history of engineering education, even in human history altogether. After centuries in which human development seemed rather easy, the dawn of the period that some scholars have described as the Anthropocene, the era of man, has brought to light a myriad of new challenges. Global warming, rampant pollution of the oceans and the air, cancer clusters due to inadequate disposal of industrial waste, and a menacing loss of biodiversity known as the sixth mass-extinction event—among many other concerns—threaten to undo much of the progress that humankind has made over the past centuries and have sharpened the distance between those living in the wealthiest parts of the world and the rest. These problems, many of which are produced by technology, must also be resolved by technologists—and that is basically to say by tomorrow's engineers. Yet the emergence of these very problems has made clear the very seriousness of the challenge confronting the engineer of the future. No longer can they imagine themselves as merely producing and implementing new technologies. They will need to understand the impacts of their innovations on the environment, and more than this, upon the society more generally. In response to the current civilizational crisis prompted by a growing awareness of the unsustainability of our current society, the United Nations has issued a list of seventeen Sustainable Development Goals (SDGs), internationally accorded upon objectives to guide humankind towards a brighter future. If everyone everywhere ought to feel themselves concerned by the SDGs, the fact that development itself has arguably been technological phenomenon (with developmental differences between nations largely overlapping with their degrees of technological development) makes the accomplishment of the sustainable development goals a task of special relevance to engineers.

The purpose of this document is to offer an overview of current ideas and practices regarding the future of engineering education as seen from the viewpoint of sustainable development, with the aim of preparing the next generation of engineers to meet and exceed the SDGs.

The following pages provide an overview of the question of sustainable development with a specific focus upon its relevance to the work of the engineer. They also consider how diversity bears on the challenge of engineering for sustainable development, arguing that diversity is not a problem for development, but, if properly harnessed, an opportunity. In order to make good on this opportunity, however, engineering education needs to attract diverse talents into engineering schools, as well as to adapt the culture of engineering itself in the name of fostering greater inclusivity. The literature review thus transitions into a discussion of the current state of the art regarding the attractiveness of engineering and engineering education. In a final section, the text turns to the concrete changes to the curriculum that are required to prepare the next generation of students to meet the challenges of sustainable development. Assuming that the specific knowledge bases required to attain sustainability will be both domain-specific and evolving, this report focuses on a transversal and skills-based viewpoint in its review of current practices. It concludes by making some recommendations for skills sets and competences that ought to be further integrated into engineering education.

Chapter 1 - Sustainable Development

It has been argued that sustainability and sustainable development are concepts that are difficult to define, even that they "mean all things to all people" (Norton, 2010). As other observers have noted (Bibri and Krogsti, 2016) the nature and meaning of the concept of sustainability and sustainable development have been hotly debated. A definition that is frequently quoted and held as affirmative (eg. Portney 2015) comes from the World Commission on Environment and Development, which defines sustainable development as development that: "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987: 39). That said, a large number of authors chose to define sustainability with respect to its contraries; emphasizing that despite a lack of clarity with respect to what sustainability is, it is clear enough what it is not: collapse and overshoot, development that oversteps the boundaries and limits that make possible the future of life (Meadows et al, 2012; Goodall 2012; Diamond 2011; Steffen 2015). As Elena Giovannoni and Giacomo Fabietti (2013) have noted, there has been a general shift in the discourses around sustainability from the 1970's to the present: earlier conceptions of sustainability were mostly derived from Malthusian ideas regarding carrying capacity (Portney 2015), while more recent conceptions focus more strongly on holistic conceptions of social and economic development, operating within what has been called the "three pillars" framework. The "three pillars model" of sustainable development (also called the three circles model (Lozano 2008) or the Triple Bottom Line (Elkington, 1997)) understands sustainable development as balancing the environmental, the social, and the economic. In some contexts (for example with respect to sustainable cities and communities) authors (ex. Sachs 2015, Cohen 2018) add a fourth pillar, governance, or a fifth pillar, culture. As is to be expected, there are a variety of interpretations of the meaning of each of these terms as well as varying accounts of their adequate prioritization (or whether there is one) (Alhaddi 2015).

It is generally agreed upon that attaining sustainability involves systems-theoretical and holistic thinking (Sachs 2015, Portney 2015). This thinking is both future-oriented and highly interdisciplinary (Costanza, 2007). Evidently dealing with such complexity always involves trade-offs, as Gray (2010) has noted. Different accounts of what counts as an adequate trade off, and so an legitimate pursuit of sustainable development, have led some to argue that there are really two sustainability paradigms: the so-called "strong" and "weak" paradigms, with the weak paradigm accepting that natural capital is substitutable for symbolic capital, and the strong one insisting that natural values are non-substitutable (Neumayer, 2013). A similar dichotomy is found between environmentalists who argue that development (or at least growth) cannot be reconciled with sustainability (eg. Jackson 2016), and those, including Nordhaus and Schellenberger (2011) and Goodall (2012), that argue that growth, when powered by adequate technological development and innovation, is fully sustainable. Some (including Sachs 2015) suggest that sustainability ought to be analytically included in the notion of development: *there can be no sustainability without development, and no development without sustainability.*

Theoretical disputes notwithstanding, sustainable development has become a major priority in international governance over the past decades. This began with the 1972 Conference on Human Environment, which subsequently led to the creation of the UNEP (UN Environmental Program). At the beginning, these programs were primarily focused on environmental sustainability, primarily pollution control, and they paid little attention to questions of development. In 1980, however, the UNEP articulated the WCS (World

Conservation Strategy), which focused on sustainable development, a notion that was further developed in the 1987 publication of the World Commission on Environment and Development (WCED) report Our Common Future, commonly referred to as the Brundtland report. The above-cited definition of sustainability-- “meeting the needs of the present without compromising the ability of future generations to meet their own needs” – was first formulated in this report. Implicit in this declaration was the idea that the current economy was unsustainable, trading off long term dwelling on the planet for short-term gains. In the 1980’s and still today the socio-technical system is overly reliant on non-renewable resources, often irresponsible with respect to the treatment and accumulation of often biohazardous wastes, organized so as to produce overconsumption and to increase, rather than decrease income and PPP disparities, without even mentioning the dangers of climate change. Further recognition of the importance of sustainability for development was accorded when the UN chose to include the “preservation of the environment” in its 2000 Millenium Development Goals. In 2015, the integration of the two concepts became yet more complete, with the MDGs becoming the SDGs or Sustainable Development Goals, a shift in language that affirms that all real development must be sustainable. In spirit, these objectives have been generally well received, though some, including Jan Vandemoortele (2018) have found the SDGs to be an example of “muddled” environmental and political thinking, tainted by political priorities, and far too weak on environmental themes (the numbers are meant to reflect the order of priority, and almost all of the specifically environmental goals are to be found at the end of the list). Though Vandemoortele is doubtless right to emphasize the way in which the current discourse around the SDG’s greenwashes over unresolved tensions between society and environment, there is no doubt that sustainable development has begun to receive political recognition.

Likewise, sustainable development has also become a major educational concern. Multiple national and international engineering education organizations, for example the French CTI, explicitly mention the need for schools to include a sustainability and an ethical responsibility component within their curricula (they must elaborate a so-called “*Plan vert”*.) While including sustainable development in education is something that is of concern to all disciplines and grade-levels (many critics insist that culture is as important as scientific development for solving environmental problems (Evernden 1985)) it is clear that the need to integrate sustainability into education is of particular relevance to engineering. This is for the very simple reason that development as it is currently understood is inseparable from technological advancement, and that many of the current problems—such as an over-reliance on non-renewable and or highly polluting resources—are products of the current technological infrastructure.

Sustainability and Diversity

Diversity is a term that is both difficult to define and is defined in diverse ways depending on national tradition. The following section attempts an overview of the current literature on diversity with the aim of both clarifying conclusions and highlighting ways in which learning how to use diversity can contribute to improving sustainability-oriented engineering education. Increasing diversity has been an increasingly important objective of political, academic, and industrial organizations over the last decades. It has been seen as a particular problem in the context of engineering education, which is in many countries one of the least diverse academic disciplines. It has also, of late, assumed an increasingly prominent place in discourses around sustainability. This section will deal with definitions of diversity, its relationship to sustainable development, and the challenges confronting organizations attempting to optimize their diversity, and current recommendations and best practices relative to using institutional diversity to train engineers for sustainable development. In closing, we will also glance over the literature regarding training these same engineers in the use and management of diverse teams, since this itself is a key skill for tomorrow's engineers.

What is diversity?

Certain groups tend to ontologize diversity, aligning it with what might appear to be fixed differences, while other traditions define diversity more pragmatically, focusing upon functional tensions and perceived differences. The first approach to diversity is dominant in the UK and Europe, where diversity is generally aligned with gender inclusiveness, as is the case in the Davies (2011) and Higgs (2003) reports in the UK and in the 2017 EU communication "A Better Workplace for All." A pragmatic and functional approach is more characteristic of US discourses on diversity. A 2011 US executive order on diversity and inclusion in the hiring of government employees, for example, mentions "population diversity" "equal opportunity for all" and "diverse perspectives," situating diversity not in fixed gender differences but with respect to what might be broadly described as perspectival differences, or to use Page's (2007) term: "cognitive diversity." As Niishi (2013) notes, the origins of diversity can be both observable (eg. gender, race, age) or non-observable (culture, cognition, education). Broadly speaking, diversity-generating differences include (but are not exclusive to): national origin, language, culture, ethnicity, belonging to organizational and professional groups, academic disciplines, gender, age, sexual identity, socioeconomic status, kinds of intelligence and religious beliefs. Viewing diversity functionally draws attention not to individual differences (say the ratio of males to females) but to ways in which difference (in general) manifests itself within the functioning of collectives.

In functional terms, any list of categories of difference is not meant to highlight differences in origin, but rather aspects of difference within a collective. It is for this reason that Knippenberg and Mell (2016) have drawn attention to what they call "emergent diversity," namely differences that emerge within the functioning of a system, even amidst individuals of similar backgrounds. Striving for additional conceptual clarity, Harvey et al (2015) and Edmonsen and Harvey (2018) speak of diversity in terms of the more generic idea of "boundaries," with a boundary being understood as the functional effect of a difference within a system. Others, including Charlan and Wachtler (1983) frame these boundaries in terms of power differentials, using the terms majority and minority, or in Barak's (2015) terms, those in the "mainstream" of a society and "outsiders." Still other researchers, including Russell and Smorodinskaya (2018), approach diversity from a yet higher degree of abstraction by aligning it with the degree of systems-theoretical complexity of a group (a diverse group is highly complex).

One argument for this functional approach to diversity is that studies have shown that the effects of differences within a group are very much a function of perception (Livermore 2016; Groysberg and Connolly, 2013). It is the way that individuals attend to the differences within a collective that render them sources of diversity, since it is only in such cases that differences can be said to impact the functioning of a social system. Nevertheless, some researchers have argued that some kinds of difference are more significant than others. Carlile (2002), for example, distinguishes between "thick" (gender, language and cultural diversity) and "thin" (experience and hierarchical) diversity. Harrison and Klein (2007) have suggested a threefold categorization of differences including: diversity of separation (opinions, beliefs, values, attitudes), variety (expertise, background, personal connections, industry experience), and hierarchical disparities (income, prestige, status, authority, power).

Diversity and Sustainable Development (the promise of diversity)

Up until quite recently (and still today in many discourses on diversity), it might have seemed that increasing the diversity of students in engineering education was primarily a moral or ethical duty, a question of remediation linked to social justice and equality emerging in response to the challenge of integrating immigrants into traditional and homogeneous societies. Encouraging diversity is considered impactful with respect to sustainable development in the immediate sense that it promises to ameliorate the economic prospects of less-favored groups. Within this framework, and particularly with respect to the vast majority of what has been written on engineering education and diversity, the mere fact of increasing the diversity of schools is seen as the problem (Delaine et al, 2016; Grimson and Roughneen 2009). Put otherwise, according to this discourse, diversity is a problem to be solved, but not a key part in the solution to the problem of innovating to accomplish sustainable development.

Recent research, however, has prompted a revision of this picture. Both theoretical and empirical research has shown that diversity increases creativity and problem-solving capacities. This means that institutions that encourage diversity should be best able to solve the challenging problems that sustainable development poses (Page 2007; Hülsheger, Anderson, & Salgado, 2009; Jackson, May, & Whitney, 1995). In theory, at least, the power of diversity stems from its multiplication of perspectives and the corresponding broadening of the likelihood of problem solvers arriving at an adequate problem heuristic (Page 2007, Sawyer 2007). Diverse groups have also been shown to consider more information and to process information more thoroughly and accurately than homogenous groups (Apfelbaum, Phillips and Richeson, 2014). In an educational context, diversity has also been shown to have beneficial effects upon student learning, not least because it assures that a wider range of perspectives will be represented within classroom discussions (Milem et al, 2005). It has also been shown that diverse schools promote open-mindedness, a cognitive attitude that has been shown to positively correlate with innovativeness (Mitchell, 2012). Attracting diverse learners to engineering education would also increase the talent base by including individuals and cognitive profiles whose capacities would be otherwise overlooked (Aparakakankanage and Tull, 2014). In addition to augmenting problem-solving capacities and increased social dynamism, research has shown that diverse groups are more likely to express sustainability-related values and are thus more likely to opt for sustainable over unsustainable but short-term economically profitable solutions (Nadeem et al, 2017; Liao et al, 2015). Diverse groups are also more likely to perceive and understand the problems experienced by minority groups (Nilsson and Jahnke, 2018)). In practice, diversity and grassroots innovation have also been positively correlated with economic growth (Phelps, 2013). Additional benefits of diversity have included higher reported satisfaction on the part of group members and higher estimations of organizational attractiveness (Eckhard and Zeigert, 2005).

In sum, the literature suggests that achieving diversity in engineering education is not an objective that stands at cross purposes with promoting sustainable development, but rather ought to be understood as a potent tool for achieving sustainable development.

The Challenges of Diversity

If increasing diversity promises a great deal of progress, the research has also demonstrated that introducing diversity within institutions is in most contexts anything but a straightforward and unproblematic procedure. Diverse teams are often conflict-prone, and, in many situations, they under-perform relative to both homogeneous teams and theoretical expectations (Olson, Walker and Ruekert, 1995; S. E. Jackson & Joshi, 2004; Kochan et al, 2003; Riordan & Shore, 1997). As Brewer and Brown (1998) have pointed out, diverse groups sometimes fail to cohere as groups, breaking down into subgroups separated by “we-they” distinctions. Barak (2015) has indicated that within poorly functioning diverse groups members belonging to minorities report feelings of exclusion despite their formal status as included. Olsen et al (2016) have pointed out that the beneficiaries of university diversity initiatives often suffer once they are included, reporting that they feel stigmatized against or undeserving because they been included only to meet administrative quotas. Observers have also noted a persistent achievement gap between members of included minority groups and those within the majority (Bauman et al 2005). As Massey et al (2003) have pointed out, minority students not only earn worse grades, but they make slower progress towards obtaining their degrees and are also afflicted with higher drop-out rates. Teachers in diverse institutions sometimes find it difficult to deal with diverse classrooms, frequently expressing the view that they are ill-equipped to handle the challenge of diversity (Woodcock and Woolfson, 2018). In sum, taking institutional advantage of diversity is not so simple as merely enrolling individuals from diverse backgrounds into currently existing engineering curricula.

Optimizing Diversity

Different cultures understand diversity differently, and it has been shown that different cultures have developed different strategies for successfully integrating institution-wide diversity imperatives (D’Iribarne, 2002; Olsen, 2016). This makes the task of formulating general recommendations for optimizing diversity a difficult one. Nevertheless, the literature does offer some indications. Almost everywhere in the US literature one finds a mantra: *no diversity without inclusion*. What is inclusion and how can it be fostered?

One of the leading voices on inclusion, Mor Barak (2014), suggests that inclusion cannot be merely a state of formal inclusion (having an official role in an organization), but must also involve informal inclusion, (taking part in discussions around the “water cooler,” lunch meetings, or other sorts of informal collective gatherings.) Diverse but inclusive institutions will have achieved a collective openness which frees members to abandon their fear of expressing themselves and to fully contribute to the collective (Hoffmann et al 2008). As Klein and Harrison (2007) put it: “It is not sufficient for a group member to improve on another's solution; he or she must also win others’ approval of the improved solution as the next best course of group action.” An inclusive institution must put into place the cultural conditions in which all group members feel that they have the right to give voice to their perspectives and opinions. As Mor Barak indicates (2015), inclusion is not *homogenization or the negation of differences*, but rather achieving what Page (2007) calls “superadditivity”: *the mutually enriching cumulation of differences*. Inclusive groups do not sublimate diversity for unity and groupthink (Janis, 1991), since attaining this kind of homogenization negates the multi-perspectival benefits of diversity. To the contrary, within an inclusive organization differences are recognized as sources of value. These organizations successfully foster a sense of both uniqueness and belonging among their members (Shore et al;, 2011). Schofield (2001) has described this state as “integrated pluralism,” a state in which multiple visions co-exist without exclusion or hierarchy.

Almost all of the literature suggests that diverse and inclusive institutions accomplish this state both through open discussion of issues of diversity and through structural transformations aimed at optimizing diversity and creating new forms of inclusiveness. The following list indicates some of the institutional strategies present in the literature:

- Leaders must performatively embody the ideas of diversity, explicitly addressing questions like inclusiveness and bias, and showing respect, sensitivity and tolerance (Henze et al, 2001).

- Increasing the cultural intelligence quotient of the group members (CQ) (Livermore, 2016) by helping them to understand and recognize the benefits of difference and diversity. Help them to acquire skills necessary for communicating with others.
- Putting in place mechanisms that encourage inter-group communication, particularly among those on the margins (Cox & Blake, 1991)
- Building connections through cooperative efforts towards mutually valued goals (Slavin ,1995).
- Collaborative efforts ought to be “ends focused” as opposed to “means focused” (Packer et al, 2018)
- Increasing transparency within the organization and address explicit and implicit biases (Galinski et al, 2015), reframe biased discourses where necessary (Ruggs, 2012)
- Practice “perspective taking” in which group members theoretically explore the situation of the others (Wang et al, 2018; Livermore, 2016).
- Reducing negative or dismissive reactions to novel or different ideas, generally shown to be more frequent in the case of ideas expressed by outgroup or minority team members (Horsey and Imami, 2004).
- Promote a multi-institutional and multi-cultural approach to problem solving across many fields (Harkavy et al, 2015).
- Seek out pedagogical approaches that are accessible to students that learn differently or who come from cultures that have different relationships to knowledge (Davis, 2014).

Diversity, Inclusion, and Engineering Education for Sustainable Development

Overall what the literature shows is that increasing the diversity of engineering education has a great deal of promise for helping meet the challenges of sustainable development. Not only is attaining diversity in general a step towards realizing the SDGs, but successfully understanding how to make diversity work will provide the human capital needed to make sustainable development happen. Yet just as confronting the challenge of sustainable development will require a radical rethinking of the engineering profession in general and of engineering education in particular, so too will integrating diversity into the engineering profession and engineering education require a serious effort at reform. Happily, both of these reforms can be complimentary, though they need not be, and care must be taken on the part of administrators and other reforming agents to assure that the complementarity between these two imperatives is maximized.

Chapter 2 - The Role of Engineers in attaining the Sustainable Development Goals

There is no question that engineers will have a major role to play if society is to achieve any or all of the sustainable development goals. This is emphasized by statements issued by the leaders of many national and international engineering organizations. Keith Howells, the Chairman of engineering firm Mott Macdonald, notes in a publication of the Royal Academy of Engineers (2017) that “Engineers will play a crucial role in delivering the SDGs.” A similar sentiment is echoed in statements issued by the WFEO (2015), the ASEE (2016), and the ICE (2018) (and is nearly everywhere voiced in the specialized literature.)

Broadly speaking, the literature on the changing role of engineers relative to accomplishing the SDGs can be divided into works that deal with specific technical aspects of the challenges confronting engineers working towards sustainable development and those dealing with the expansion and transformations in the role, knowledge, and skills of the engineer generated by the challenge of sustainable development. This literature review will largely pass over the contributions of the first type, judging that literature to be both too extensive and too specific for a project dedicated to the more general transformation of engineering education, in order to focus more closely on transversal themes and in particular on ways in which engineering for sustainability intersects with questions of diversity.

To begin with, however, we will note in passing a few of the general tendencies expressed in the specifically technical literature dealing with the most promising fields where new technologies seem poised to aid in the accomplishment of a more sustainable future.

General Tendencies in the Technical Literature

One feature that is noteworthy across almost all domains is the weight of expectation placed on computing, smart technologies and connected objects. This is particularly extreme in the case of sustainable cities, with the term smart city frequently being used as a synonym for sustainable city in much of the literature (see Comer, 2016; Batty et al, 2012; Bibri and Krogstie, 2016; El Nuami et al, 2015). This urbanist fascination with smart technology is far from an isolated case, however, with the turn towards smart systems thinking being also present in domains such as sustainable agricultural development (Campell et al, 2018) and Industry 4.0. In almost all domains, information technology is presented as a way forward, even with respect to domains such as the conservation of cultural heritage (a specific target of the MDGs, if not specifically mentioned in the SDGs) (Xiao et al, 2018). Another noteworthy trend in the literature is the call for an expansion of the traditional domain of engineering applications. Clifford and Zahman (2016) for example, argue that engineering expertise needs to increasingly be applied to the medical field (which has up until recently been dominated by medical school graduates.) Others, including (Mora et al, 2018; Jessell et al, 2018) have argued that engineers need to work harder to provide technological solutions to expanding quality education worldwide. A further recurrent tendency in the literature is the insistence upon the importance of innovation (or as Gauvreau (2018) puts it, “idea generation”).

Changing Roles of the Engineer

If the application of technology to concrete developmental problems falls within the traditional mandate of the role of the engineer, there is ample literature testifying to the need to expand and alter the conception of the engineer in order to meet the challenge of the SDGs. Already in 1998, Clift was signaling that in order to power sustainable development engineers needed to step out of their traditional role—which was confined to the focusing primarily on the economic pillar—*to develop awareness and skills relative to the two other pillars of sustainable development*.

Most observers seem to agree that the new role for engineers as addressing social and environmental concerns requires not only obtaining new kinds of knowledge, but also new sensitivities to the complex ramifications of engineering projects. Halbe (2015) has even suggested that sustainable development requires a shift in the entire epistemological foundations of engineering knowledge and know-how. Distinctive of this shift, for Halbe, is the fact that within the new paradigm engineers need to move from seeking basically technical solutions to integrated, adaptive, and participatory ones. *This means that the engineer is not so much the knower and problem-solver as the orchestrator of collective performances of problem solving among diverse actors*. Many, including Halbe (2015), Lambrects et al (2019), Zhang (2016), Cukwul et al (2014) and Cruickshank and Fenner (2007) emphasize the key role of systems thinking in the practice of sustainable engineering. Others, including (Cohen, 2018) emphasize the importance of circular thinking. Many, including Halbe (2015) and Fekete and

Bogardi (2015) suggest that engineers need to pay additional attention to assessing risk (particularly environmental and social impacts). Lambrects et al (2019), describe this as "foresight competence", echoing the importance accorded to future literacy and anticipation competence among educated people in general by a recent major UN study (Miller, 2018). As Lambrects et al (2019) suggest, this requires a solid foundation in strategic foresight thinking, strategy game analysis, Imagineering, and situation modeling (Rogers, 2018; Ratliff, 2018). It also requires a significant amount of historical knowledge, including knowledge of the interactions between natural and social systems (see Costanza et al, 2007). Ramifard and Trollman (2018) have also claimed that the new engineer needs a deeper grounding in the "real life" impacts of engineering projects. Of particular importance are seen to be knowledge of the interactions between technical systems, natural ecosystems and social systems, with a frequent emphasis on the importance techno-eco-social awareness. Not to be ignored is a cultivation of the understanding of the broader impact of technology upon human beings, including with respect to themes like gender equality (SDG 5) (see Wacjman, 2010; Falkner, 2001) and an understanding of the social implications of technological developments upon the future of work (SDG 8) (Ross, 2016; McAffee and Brynjolfsson, 2011). Historical knowledge regarding the role of technologies in building what Paul Smith Lomas (RAE, 2017) has called "technology injustice" is evidently also important, particularly for engineers interested addressing SDG 1. All of this suggests that *we should think of future engineers as having socially situated bodies and feelings as opposed to imagining them to be abstract and disembodied problem solvers*. It also implies that *in the future the role of the engineer is not only restricted to being a creator of technologies, but also to being a critic of both specific technologies and of the inherited ideological vision of technology within modern society.* Tomorrow's engineer will not only take on the role of solving immediate problems; but will additionally assume a leading role in foreseeing the problems generated by their own solutions and attending to the complex social and environmental implications of an innovation over the entire lifespan of the technology. Put otherwise, *engineering for sustainability requires a broadening of the scope and temporal horizon of engineering practice.*

Another feature that is common in the literature is a call for engineers to assume a role *not merely linked to the development and implementation of technology but also tied to communication and mediation, sometimes in the context of dealing with or harnessing the power of diversity*. This should be obvious given that engineering is becoming an increasingly globalized profession (Katehi, 2005), and that many of the sustainable development goals are by definition global. In this context, Lambrects et al have argued that engineers need to learn how to "use diversity" making the most out of diverse teams in order to optimize their problem-solving potential (Lambrects et al, 2019). This is echoed (among others) by Annan-Diab and Molinari (2017) and Halbe (2015). As Mallet (2018) has argued, using diversity implies making use of cultural, social, and natural knowledge as sources of innovation thinking. It also involves mastering what Ramifard and Trollman (2018) describe as "user-centric" innovation solutions for an increasingly diverse world. Using diversity demands a participatory approach to problem solving, and it also means that future engineers can *imagine different roles for the engineer and engineering expertise within diverse teams*. One way of illustrating these potential new roles is to be found in Goldberg and Summerville's (2014) discussion of the integration of diversity into the curriculum at Olin College of Engineering. They speak about extending engineering education to involve six different types of minds, and it is doubtless the case that the future role(s) of engineers within sustainable organizations will reflect these different kinds of minds; that is to say that in *the sustainable engineering of the future there will be roles for not only of traditional analytically-minded engineers but also from design, linguistic, people, body, and mindful-minded engineers.*

Understanding the role of engineer as communicator and mediator can include the idea that engineers *ought to assume roles in politics or even in public education*. 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. Some authors emphasize that communication must *not only be understood to occur through words but also through actions*. Mair (2018), for example, has called on engineers to not only solve problems but to "inspire" change by example, *insisting that they need to be leaders and change-makers*. Chukwul et al (2014) suggest that engineers need to be "enlighteners," stepping out of their traditional role of solving problems through technology and instead accepting a *role in which they articulate and disseminate good practices linked to wise usage*. Another related role for the engineer of the future (analyzed by Lazzarini et al 2018 in a study focused on engineering academics) is that of "connector," which is to say *the engineer of the future will be a figure who mediates between diverse groups with different knowledge and experience bases, bringing out the best in each to put diversity to work.*

In sum, the future role(s) of the engineer will involve a broadening of the scope of engineering practice and concern, and a loosening of the very narrow connection between engineering and technological problem-solving to include a far broader and more social conception of the vocation of the engineer.

On the Attractiveness of Engineering Education

Attracting and engaging future engineers has become a central topic and a priority not only in engineering education and in business and industrial organizations but also for the whole of society and indeed for anyone concerned about achieving the SDGs. Future engineers must take a central role in the society if we are to resolve the next decade's sustainable development challenges in a direct or indirect (eg.: more efficient sustainable resources uses, contribution to the digital education,…) ways (Tjoa and Tjoa, 2016). Today's globalized and digitalized world needs more than ever well-trained and talented engineers to ensure technological, economic, social and societal progress (Duderstadt, 2010). Due to the growing demand for engineers in industry 4.0, and a lack of interest in engineering among young people, many regions are currently experiencing a chronic shortage of engineers, and this is likely to remain a persistent and even worsening problem over the next several decades. To satisfy the labour market demand, universities are being encouraged to increase their production of engineering graduates (Arlett et al, 2010). Yet it is becoming more and more difficult to convince talented students to enroll engineering schools, and there is in turn a paucity of highly-skilled and work-ready engineers available to work at business and industrial organisations.

Not only are more engineers required to meet the SDGs, but the promise of diversity means that attracting individuals from groups that are currently underrepresented forms both a challenge and an opportunity for those involved in engineering education. As we have seen, harnessing diversity can be a key to developing the kinds of innovative solutions required for achieving sustainable development. Attracting diverse students to the engineering profession must thus be a key objective for the future. This point becomes even more critical if we keep in mind the collateral benefits associated with the diversification of the engineering workforce, namely the remediation of the above-mentioned scarcity of talented engineers by widening the pool of potential candidates, as well as the general amelioration of the lives of individuals within socially marginal groups via access to secure and well-paid employment.

The following pages will examine the general research on the problem of attracting students into engineering education, with a particular focus on the challenges and prospects for motivating students from non-traditional backgrounds to enter into this profession.

As outlined by Schrey-Niemenmaa and Jones (2011), the attractiveness of engineering education is a multi-facetted problem whose solution will come not only from academia but also from the involvement of other stakeholders. More particularly, the involvement of industry could reinforce students' attraction and graduation rates as well as improve their work-readiness and employability perspectives (Male and King, 2014; Arlett et al, 2010).

One currently-employed short-term solution, is the ongoing practice of recruiting engineers from the international labour market mainly from emerging countries. This resolves short-term recruitment problems and also increases companies' diversity, creativity, and competitiveness. However, it does not resolve the existing scarcity problem, and it likewise risks aggravating the existing shortage in the engineering workforce, since it has been shown that filling engineering jobs with foreign workers dissuades European students from joining the engineering profession, since they no longer imagine themselves as corresponding to the imagined category of "the engineer." (Katzis et al, 2018). It is obvious the most of industrialised European countries have to find a long-term sustainable solution to this problem without further delay by attracting and involving the national population in engineering education.

Why are young Europeans, and particularly young Europeans from diverse backgrounds, not choosing engineering? In their study, Johnson and Jones (2006) identified the following barriers to picking up engineering studies:

1. *The curriculum is difficult*-- it requires hard work that needs prior preparation in the secondary education years.
2. *The curriculum is often densely packed and inflexible*-- it is difficult to adapt the curriculum to individual interests and professional projects.
3. *Other paths to good jobs are easier*—jobs in business and law, for example, require less effort and are better remunerated.
4. *Engineers frequently treated as commodities by employers*—Engineers are often seen as cogs within a corporate machine, and as such they are susceptible to being laid off when financial results stagnate.
5. *Traditional entry-level jobs are being offshored to consulting companies at lower salaries.* The same is true of higher-level engineering jobs. Where companies once outsourced only manufacturing, growing levels of engineering expertise in countries such as China mean that companies can offshore both design and production.
6. *Media reports indicate instability in employment opportunities*—This spreads a negative image of the engineering profession.
7. *Lack of diversity*—The image of the engineer as a white male is persistent, and women and minority populations are still vastly underrepresented in current student populations.

As highlighted by Becker (2010), the media is not the only influence on young people's decisions not to choose engineering. Some major factors influencing their decisions include:

- the status and image of engineering,
- current social ideas about engineering, including the ideas about engineering expressed by family, teachers and peer groups (Alika, 2012; Carnasciali et al 2013; Woolnough, 1994).
- the attractiveness of the available career opportunities

- the financial rewards in comparison with alternative careers

Focusing on the image and status of engineering profession, the results of the workshop of the SEFI working group on Attractiveness of Engineering Education (Kövesi and Schrey-Niemenmaa, 2017) show heterogeneous images of engineering all over in Europe. The image of the engineer can be very positive (e.g.: in Finland, Denmark, Sweden), in other countries engineers are treated with respect but no more (e.g.: in Deutschland, Austria, Italy) while in France the position of the engineer is highly prestigious (e.g.: in France, Belgium) in stark contrast to the rather low-class image of the engineer in some other nations (e.g.: in the UK, Ireland). This broad diversity in the social perception of engineers has had a significant influence on young people choices as is indicated by the results of a European report (EU, 2008) on the willingness of young people to study engineering. A persistent challenge for motivating engineers is a perceived asymmetry between the difficulty of engineering studies and the level of compensation enjoyed by those working in engineering fields. Compared to other professions, studies in medicine and engineering were perceived as requiring the most effort. However, the perception of a compensatory pay level for medicine (64%) appears clearly as the most well-compensated profession, and while engineering (23%) comes in behind law (28%) and management (24%).

Focusing on members of minority groups, which studies (often American) have shown to be particularly under-represented in Engineering and other forms of STEM education, we note some additional barriers. These include:

1. *Lack of preparedness*

   Students from groups underrepresented within engineering schools tend to suffer from having been poorly prepared by their elementary educations. They come from low progression neighborhoods, with inferior schools and suffer from other kinds of disadvantages such as absent parents and the need to work in addition to attending school (Bannerjee, 2016).

2. *Differences in ways of knowing*

   According to Brown (2004), different cultures have different epistemic traditions. Students from minority groups report feeling uncomfortable talking about knowledge according to the standards of STEM, and they may find the kind of expression that is practiced in STEM is unlike the normative forms of expression practiced by those in their social groups (Brandt, 2008; Olitsky, 2006). This can keep people from identifying with STEM, a point that is exacerbated by a particular emphasis within engineering on innate capacities such as IQ and talent, indexes that have themselves been shown to be culturally biased (Carleone and Johnson, 2007; Dai and Cromley 2014). The question of differences of knowing also bears on the challenge of attracting non-traditional types of thinkers into engineering education. As Goldberg (2014) has noted, the traditional vision of the engineer has only overlapped with the analytical mind, but there is space in engineering for the design mind, the linguistic mind, the people mind, the body mind, and mindful mind as well.

3. *Lack of a feeling of belonging*

   Studies have shown that a feeling of belonging correlates highly with student's choice to persist in a career in engineering (Lee et al, 2006). Several studies of women in STEM have described a feeling of "isolation" as playing a key factor in individual's choices not to pursue a career in STEM (Hewett et al, 2008). Other studies have shown that women feel only ambivalently about whether they belong in the key engineering field of computer science (Cheryan et al, 2009). This lack of belonging has also been shown to correlate with a lack of self-confidence among members of minority groups, a lack that highly correlates with low performance (studies tracking increases in self-confidence have also demonstrated performance increases) (Seymour et al, 2004).

4. *Racial and gender stereotypes*
If the stereotypes regarding engineers vary from country to country, there are few countries in which the image of the engineer overlaps with that of members of under-represented groups. To paraphrase Malcolm (2016) "black gay men aren't engineers." The same has been shown to be the case with women, LGBT+ and members of nearly any minority group (Cech, 2011).

How should we promote engineering studies to attract more talented young people? Let us look at some work on why people chose the jobs that they do in the first place.

One obvious candidate is interest. According to the results of ROSE (The Relevance of Science Education), interest is one of the main decision-making factors in young people's educational choices. Yet with respect to the data the correlation between possessing interest in themes related to engineering and choosing to become an engineer is unclear. According to one European Comission study (EC, 2008), 54% (EU27 average) of the young people questioned declared themselves as having no interest at all in studying engineering. This result is surprising given their generally high-level of expressed interest (more than 90%) in science, new inventions and technology. This widespread interest in science and technology has been confirmed by Sjøberg et al (2010). So why do students who are generally interested in science and technology would not choose to pursue engineering as a career? According to the above-mentioned ROSE study, people chose to work in a domain that allows them to:

- use their talents and abilities
- make their own decisions
- have lots of time for friends
- earn lots of money

One might conclude from this that students, though interested in engineering subjects generally, *don't feel that they have the required talents and abilities, don't like the fact that many engineering programs offer little space for personalization and self-realization, and are repulsed by engineering study because it appears to offer insufficient time to cultivate friendships.* Money, though a factor (and despite what we have noted above), ought probably to be discounted here. At least in the US, the jobs with the highest starting salaries are engineering jobs. In fact, a recent study by Miller et al (2015) showed that positive economic outcome expectations played major role in student choices to opting for engineering studies (the students believed that they would find work, have good working conditions, etc.). It is essential to note also that *educational decisions also significantly influenced by family traditions and antecedent experiences.* A recent study by Painter et al (2017) concluded that the three main decision factors in choosing an engineering major are:

- expression of an interest in the subject matter,
- influence of the family (encouragement or having an engineer in the family)
- prior experience with engineering related activities (eg., working with robots).

Note well that the expressed importance of family and experiential antecedents as well as the social ("friends") dimension of career choice pose significant challenges for the diversification of the profession. Self-evidently, individuals coming from groups currently under-represented within the profession are unlikely to have family members that are already engineers, and it is likewise true that these same individuals are less likely to have friends involved in the profession than would be the case with individuals coming from currently well-represented populations. It is also true that individuals coming from a population in which the talents and abilities related to engineering have as yet been largely left fallow are unlikely to imagine themselves as possessing those talents and abilities. *This (and other attractiveness issues) in engineering education would clearly be addressed by creating a more flexible curriculum better adaptable to the diverse learning methods and capacities possessed by different kinds of students.*

Of course, it is important to take into consideration that engineering is a very heterogeneous discipline with significant divergences between specialties. This means that differing disciplines attract different types of students and for different reasons (Filipkowski, 2009; Hrad and Zeman, 2010).

On an optimistic note, there is reason to believe that the importance (and perception of the importance) of engineering work in the promotion of a sustainable future can be a major factor in motivating students to study engineering. A 2012 study by Reis et al.. polled the perception of engineering among American secondary school students and incoming freshman engineering students. According to their results, 30% of secondary students considered that engineers are important for their country's development, while a more than 70% for freshman engineering students believed in the importance of their profession. These results indicate clearly that those choosing engineering as a profession often do *so not because of their ideas about money or social status but because of the fact that they perceive the work of the engineer as meaningful.* This accords well with recent work in motivational theory. Drawing upon broad spectrum of research in psychology and business, Pink (2009) has demonstrated that human beings tend to be more effectively motivated by a sense of the importance and value of their work than they are by what they will earn by doing it, what he describes (building on the work of Amabile and Hennesey (1998)) as "intrinsic motivation" as opposed to "extrinsic motivation." Thus, increasing the connection between engineering education and achieving sustainability and cultural diversity ought to heighten the intrinsic interest and value that potential students see in engineering as a career. As a matter of fact, the idea of contributing to future sustainability has already been found to a motivating factor for attracting female students and other minority groups to the engineering profession (see Godwin et al.'s (2016) study on students from 50 US institutions.)

In the framework of ATTRACT Erasmus+ project ("Enhance the Attractiveness of Studies in Science and Technology") within a EU Lifelong Learning Programme, the following good practices were identified as useful for motivating students to study engineering (Attract, 2012):

At the national level:

- Actions for promoting engineering education
- Actions enhancing the public image of engineering
- School guidance (especially in secondary schools)
- Science centers and museums
- Development of ICT in schools
- University offered courses and workshops (carried out in summer)
- Teaching programs (to make science interesting and appealing for young people)
- Students' competitions
- Conferences, seminars and fairs to promote engineering occupation and career
- Websites and media coverage (for giving advice, information and support people interested in this topic)
- Carrier guidance offices (available at secondary schools)

At the institutional level:

- Visits to secondary schools (supported by student ambassadors)
- Secondary school open houses and visits
- Fairs (promotion of tertiary educational opportunities)
- Internships and summer programs
- Websites (for providing information about the programs)
- Girls' week/day and summer courses (to attract more female students)
- Mentoring programs (to support women becoming engineers).

These actions for promoting engineering education are well established in most European countries, and they play an important role in spreading information and building a positive image of engineering.

Some additional efforts, particularly aimed at attracting members of currently under-represented groups have included:

1) *Promoting a more inclusive image of STEM, including alternative approaches to STEM teaching* (Rouychoudhury et al, 2005). This can include inspiring the young through mentoring by successful members of their own communities (Amelink 2004). Goodwin et al (2016) have concluded that in order to do this it is not only important to consider each underrepresented group individually, but that it was important to distinguish between different races and ethnicities within a specific gender which also revealed significant differences.
2) *Affordability*. Though the costs of a STEM education vary from country to country, students who need to work as well as study are at a particular disadvantage when it comes to matriculating into and succeeding in engineering programs (National Academy of Sciences, 2010). In France, for example, despite the fact that engineering education is generally inexpensive, there is still a significant investment required of students to even participate in the competitive entry exams.
3) *Expanding the support system*. Efforts need to be made early on to STEM improve the education available to students in historically low upward mobility and minority groups. This support should take into account different ways of learning and should aim to help students recognize the value of their diverse background knowledges and experiences, including an augmented emphasis upon the importance of creativity and diversity within the practice of STEM learning (Sithole et al, 2017).

It is important to note that engineering schools need not simply to attract students but attract highly motivated and assiduous students. We feel that this can be done by focusing on prospective learners' intrinsic motivation to contribute to meaningful projects like meeting the SDG goals. It is widely recognized that engineers have a central role to play in sustainable development, though this role is clearly to be expanded and developed in the future. Making a place for diverse learners within engineering schools will help to both further societal progress towards meeting the SDGs and help to invent the future roles that engineers of diverse capacities will come to play in a sustainable society.

Chapter 3 - Future skills and competencies in relation to sustainable development

This section of the literature review aims to focus on state-of-the-art knowledge on what skills are required of engineers to solve the Sustainable Development Goals (SDGs). It is here that we transition from relatively abstract objectives and ambitions towards nuts and bolts considerations regarding the concrete content of tomorrow's engineering curricula. In this survey we will try to bring out what skills are required to meet the sustainable development goals, always attempting to highlight the ways in which including the development of these skills within engineering education can likewise contribute to increasing the attractiveness and diversity of the profession.

As there is limited literature on engineering skills related to SDGs in particular, a more rounded landscape on skills and competencies related to Sustainable Development (SD) is presented here. Much of the work presented here is a response to calls for reform in engineering education which have aimed at insuring that current students are equipped with the relevant skills to meet future societal challenges (UNESCO, 2010; ASEE, 2013; Wulf, 2008; Miller, 2015). It goes without saying that there is still a great deal of debate and disagreement in the literature.

Definition of skills and competences required for SD

Firstly, in order to explain what we mean by skills, let us refer to the European Qualifications Framework (EU, 2018; Cedefop, 2014) "Skills: ability to apply knowledge and use know-how to complete tasks and solve problems. Skills are described as cognitive, involving the use of logical, intuitive and creative thinking or practical involving manual dexterity and the use of methods, materials, tools and instruments" (Cedefop, 2014, p.227). Currently, skills are often further specified as transversal skills, soft skills, transferable skills, 21st century skills, professional skills and employability skills. An alternative, and often synonymous term is competencies. For the purposes of this study we will very broadly use the term "skills" and "competencies" to indicate abilities that can be taught over the course of an engineering programme. *Our aim is to enumerate the skills necessary to meet the challenge of sustainability, and as best as possible to at the same time meet the challenges of diversity.*

That said, it is important to recognize that in the context of sustainability education skills mean nothing without the proper attitudes and values, and that capacity to use one's skills to accomplish a task often depends on the possession of knowledge and understanding. To know or care about the future of the planet is a precondition for choosing to apply our capacities to the end of pursuing sustainable development, even if this caring is not in itself a capacity or a skill. Segalas et al, (2009a) for example, suggests that skills and abilities need to be coupled with attitudes, knowledge, and understanding, with an attitude being defined as "a complex mental state involving beliefs, feelings, values and dispositions to act in certain ways." (Segalas, 2009a, p.18). *Put otherwise, even the best skills-based approach will only be effective within an institutional culture that fosters and promotes values compatible with sustainable development.*

Theoretical Frameworks and Meta-Categorizations of the Sustainable Development Skills

It is worth noting that the skills requirements for engineering graduates have differed substantially across time. Indeed, several authors have suggested that the skills approach tends to yeild “laundry lists” without any transparent selection criteria Wiek et al, (2011). That said, it is clear enough that current lists of skills generally reflect the desires and motivations of specific stake holders, be they industry actors, accrediting organisations, Higher Educational Institutions (HEIs) or the students themselves. While we do not expect to be able to provide a definitive list of sustainable development skills, we do feel that the notion of working towards sustainability can help achieve a certain degree of focus, particularly if our effort is coupled with an adequate vision of the aims and nature of engineering education.

This approach, which we might say takes a more holistic or values-based approach to skills finds some resonances in the current literature. Jamison et al (2014), for example, have highlighted the fact there are multiple understandings of the nature and objectives of engineering education, which in turn yield different conceptions of engineering, engineering competence and the role of universities and learning itself. They highlight at least three: Academic, Market Driven and Integrative. According to the authors, only the last of these, which is characterized by hybrid learning, and which includes not only the scientific and the technical, but the environmental and social dimension of engineering in one comprehensive form of education, is compatible with sustainable development. Likewise, Mulder et al. (2013) have called for sustainability to be integrated across the curriculum, such that the institution itself reflects a whole-systems approach both to what it teaches as well as how that teaching happens. In other terms, sustainable development needs to be a meta-context as opposed to an individual aspect of engineering education, not one subject or one skill but part of every aspect of how engineering happens.

That said, some authors offer somewhat less ambitious in their proposals, focusing less on the vision and vocation of education as such and more on the categorization of the kinds of skills necessary for solving sustainability-related problems. Wiek et al, (2011), for example, offer a literature review of selected peer-reviewed publications from which they deduce five key competence domains for sustainable engineering. These include: systems thinking abilities, anticipatory competences, normative competences, strategic competences and interpersonal competences. In a similar project, Brundiers et al, (2010) grouped the key sustainability competences in three clusters. The first is a strategic knowledge cluster which includes anticipatory, normative and action-orientated competencies. The practical knowledge cluster includes skills necessary for linking knowledge and action, while the third, the collaborative cluster, focuses on working with people.

In conclusion, we can say that in the ideal case a skills-based approach to engineering educational reform would be coupled with a holistic transformation of engineering education as such, but that a less ambitious approach to developing SD skills ought, at the very least, provide students with skills that allow them to strategize, to enact, and to communicate. None of the existing literature specifically addresses the intersection of diversity, sustainability, and attractiveness with respect to the consideration of the skills necessary for forming future engineers. In the following we will go more deeply into the specific skills that fall under these broader skills-categories. In order to do this, we now turn to a review of currently existing national projects and local accrediting body requirements. We also present the practices of some current programs (summarized in Table 1), and a list of competences frequently mentioned in the literature (summarized in Table 2).

Barcelona Declaration

The 2004 International Conference in Engineering Education for Sustainable Development (EESD, 2004) issued the Barcelona Declaration, a call to action for higher education institutions to create a holistic education system, which would take into consideration how engineers interact with others in their professional lives. This declaration includes a list of sustainability competences that for engineers. The list includes the ability to interact with society in different cultural, social and political contexts, with a specific emphasis on the capacity to work in multidisciplinary teams, and an aptitude for listening to all stakeholders and integrating their views into proposed solutions using a holistic approach to problem solving problems that is respectful of universal values and ethics (EESD, 2004).

Engineer of 2020

In 2001, the American National Academy of Engineering (NAE) undertook an “Engineer of 2020” project. Its aim was to describe a vision of engineering and the work of an engineer in 2020 and to review engineering education with a view to determining what would need to be done to prepare engineers for the future. Thus this project does not specifically address that question of sustainability, or diversity, but does provide insights into some of the core skills that were expected of engineers at the turn of the century. This project included consultations with experts from both the academy and industry, and the final report listed ten attributes that engineers should have. The attributes include strong analytical skills, practical ingenuity, creativity, communication, business and management, leadership, high ethical standards, professionalism, dynamism, agility, resilience, and flexibility and to be lifelong learners (NAE, 2004, p.56)

Attributes of the Global Engineer

Another American project, “Attributes of the Global Engineer” Project (ASEE, 2015) sought to define the competencies and characteristics needed by engineers to effectively live, work and perform in a global context. This project was set up as a subgroup of the American Society of Engineering Education (ASEE) council. The list was divided into five categories; Technical, Interpersonal, Professional, Personal and Cross-Cultural Understanding political, social, economic perspectives, language fluency and the interdisciplinary perspective are aspects highlighted within the cross-cultural domain. While this project does not specifically address the question of sustainability, it does offer interesting insights into what skills might be most key for engineers hoping to best use diversity.

Accrediting bodies

At a national level, many accrediting bodies have included sustainable development competencies within their accreditation criteria. Many countries align with the International Engineering Alliance Graduate Attributes and Professional Competencies agreement which sets out the graduate attributes and professional competency profiles for three professional tracks: engineer, engineering technologist and engineering technician (IEA, 2013).

Engineers Ireland is the accrediting body for engineering programmes in Ireland and for the Bachelors Degree in Engineering has seven Programme Outcomes (PO), defined as what students should learn, understand or appreciate as a result of their studies. The first four POs could be considered of a technical nature or the core of engineering: knowledge of maths and sciences, ability to solve problems, design components and conducting experiments. Three POs however acknowledge some of the more non-technical skills required of engineers; ethics, the environment, work in multidisciplinary teams, lifelong learning and communication with society (Engineers Ireland, 2015). Furthermore, in a recent policy statement regarding the impact of Industry 4.0, Engineers Ireland reaffirms the importance of social skills including team building and communication in addition to multidisciplinary work as core requirements within degree programmes.

The Engineering Council in the UK has specified six broad areas of learning outcomes for Bachelor of Engineering Programmes; Science and Mathematics, Engineering Analysis, Design, Economic, Legal, Social, Ethical and Environmental context, Engineering Practice and what is termed Additional General Skills. The economic, legal, social, ethical and environmental category specifically highlights "Understanding the requirement for engineering activities to promote sustainable development" (AHEP, 2016, p.13).

In Finland, the Finnish Education Evaluation Centre (FINEEC) are responsible for accrediting programmes and outline programme learning outcomes which describe the knowledge, skills and competencies that Bachelor of Engineering students should possess. These are split into five key areas: Knowledge and understanding, Engineering Practice, Investigations and information retrieval, Multidisciplinary Competences and Communication and Team working. Specific reference is made to multidisciplinary competencies and the awareness of societal implications of engineering practice. Furthermore, under the heading of teamwork, the importance of working in a national and international context is highlighted.

ABET, the accrediting organisation for the USA and some other countries, identifies 11 Programme Educational outcomes (PEO) for BA programs in engineering. Similar to Ireland, the PEO (a,b,c,e,k) relate to technical skills, but specific PEOs exist for working on multidisciplinary teams, ethics and professional responsibility; communication and understanding, the impact of engineering solutions from an environmental, economic and societal context. Within ABET, there is also mention of working in a global context and having a knowledge of contemporary issues, outside the realm of engineering (ABET, 2015).

Finally, the CTI which holds responsibility for accreditation programmes in France (but is also active in Belgium, Bulgaria, Burkina Faso, China, Vietnam, Morocco, Switzerland and Spain) also includes economic, social, environmental and ethical awareness. Communication skills and international awareness are also included. Specifically, the accreditation criteria note that graduates should develop an international cultural mentality and not only should graduates have a good command of the English language, but that a third language is strongly recommended (CTI, 2017).

These accreditation requirements show commonality in the development of communication skills, not only with engineering but with society as a whole, the importance of ethics and professional responsibility, working in teams and care of the environment and reference to the importance of societal implications of engineering work. None of these, however, reflects the kind of thorough-going reform of the vision of the engineer that would be entailed by reconceptualizing the engineering skill-set in terms of the single and overaching objective of accomplishing the SDGs.

Current practices in Higher Education

Whilst the idea of Sustainable Development in Engineering Education has been around for a while, the extent to which it has been introduced into curricula is varied, if the general picture suggests that there is everywhere room for progress. In lamentably many cases sustainable development is integrated into the curriculum in the form of specific subjects. Table 1 presents a picture of different teaching approaches used in various HEIs in relation to incorporating sustainable development into engineering programmes. This work builds on other literature reviews by Byrne et al, (2010) and Thurer et al, (2018) both of whom also summarise sustainable development initiatives in engineering programmes by country/region.

Table 1. Examples of teaching practice related to the integration of sustainable development in engineering programmes

Author	Details
Byrne et al, (2010)	Summarises Engineering Education Sustainable Development Initiatives by country and region up to 2009.
Thurer et al, (2018)	Summarises case reports of universities where implementations have occurred up to 2016.
Azapagic et al, (2004)	Case studies with detailed instructions which can be used in engineering modules to enhance sustainable development education. Topics include; water and waste water management, air pollution, chemical processing power and energy sources and social and ethical dimension of mining operations.
Richter and Paretti, (2009)	Interdisciplinary case study on a Life Cycle Analysis of engineering solutions module.
Bernstein et al (2011)	Implementation of a sustainable design critique aspect into a product design course. Study was a success, but sustainability was considered a secondary aspect of the product design, rather than an integral part of the project.
Goldberg (2014)	Integration of collective social welfare projects into the curriculum. Working together with a group of peers and a faculty coach, and learning through doing, they set out to discover within themselves the skills and competencies necessary to bring about positive social and environmental change.
Schmidt et al, (2015)	STEEP (Social, Technological, Economic, Environmental and Political) model, a methodology which considers a systems approach to problem solving using life cycle analysis and risk analysis which considers the complexity of engineering problems resulting in a more sustainable and holistic engineering solution.
Fitzpatrick (2017)	Exploration of social and economic reasons behind specific technologies in particular modules, debates, case studies, research projects including aspects of the environmental and social domains, Lecturer carbon footprint project, encouraging students to reflect on the SD education they have received when deciding upon future careers, Introduction of ecological economics topic in final year module.
Sanchez - Carracedo et al, (2018)	EDINSOST (Education and Social Innovation for Sustainability) Project, involves 10 Spanish Universities, and looks to integrate sustainability into the curriculum by considering different learning and teaching strategies. The researchers created a sustainability competency map which can be used to define learning outcomes for sustainability within a degree programme. The map is split into holistic sustainability issues but also includes specifically environmental, social and economic competences.
Holzer et al, (2018)	First year interdisciplinary program called "Global Issues" which has 6 themes; Climate, Communication, Energy, Food, Health and Mobility. Taught by both a technical and a social human science teacher to offer students a view of global challenges in an interdisciplinary way.
Kovesi et al, (2018)	Transdisciplinary Case Study approach, which sought to increase awareness and a better understanding of sustainable innovation and entrepreneurship in students. The project created open access teaching materials which specifically included case studies related to the SDGs.

There is undoubtedly a range of practices ongoing in engineering programmes around the world and the aim of each of these practices is to prepare engineering students with the skills and competencies to resolve sustainable development issues. Next we present a summary of the skills and competencies noted in the literature with regard to sustainable development. Table 2 summarises some key texts on sustainable development skills and competencies within recent literature. Refer also to Hasse (2014) for an overview of skills requirements in papers published up to 2010.

Table 2: Skills and competencies of engineers in literature specifically related to Sustainable Development

Author	Skills and competencies
Haase (2014)	Hasse presents a systematic literature review on assessment of sustainability related activities, competencies and approaches. Appendix A2.
EESD, (2004)	The list includes an ability to interact with society including different cultural, social and political contexts, the importance of working in multidisciplinary teams, and listening to all stakeholders and using a holistic approach to solving problems whilst considering universal values and ethics (EESD, 2004).
Katehi, (2005)	Analytic skills, problem-solving skills, design skills, creativity and flexibility, appreciate the impact of social/cultural dynamics on a team environment, communicate effectively and how to think globally.
Svanstrom et al, (2008),	Advocates that learning outcomes should not only refer to knowledge and skills, but also to awareness, attitudes and values. Skills development should include; ecosystems and the human condition, systemic thinking, interpersonal and intrapersonal skills development and a strong emphasis on change agent skills.
Segalas et al, (2009)	Self-learning, cooperation and transdisciplinary SD problem solving, systems thinking, critical thinking and social participation were raised as key skills and abilities, whilst responsibility/commitment/SD challenge and respect/ethical sense/peace culture and concern/risk awareness were the outcomes of the attitudes/competence analysis.
Brundiers et al, (2010)	Key sustainability competences in three clusters. The first, the strategic knowledge cluster includes; anticipatory, normative and action-orientated competencies
Mulder et al (2010)	Interdisciplinarity, systems approach, long term consideration of solutions, importance of complexities of social setting,
Wiek et al, (2011)	Systems Thinking competence, Anticipatory competence, Normative competence, Strategic Competence and Interpersonal competence
Polastri and Alberts, 2014,	Socio-economic, environmental, and ethical skills.
Streiner et al (2015)	Risk identification and mitigation, designing a system to meet desired needs, understand different cultures, work on international teams, communicate cross-culturally, work on global problem,/have a global mindset, live and work in a transnational engineering environment, demonstrate world and local knowledge, understand international business, speak more than one language

In the following we attempt to go into slightly greater depth in terms of specifying the skills necessary for accomplishing a certain number of sustainability related objectives.

Globalisation and Working with Diversity

Many studies discuss the importance of globalisation, or working internationally (Warnick, 2011; Downey, 2006; Nasr, 2014; Polastri and Alberts, 2014; Katehi, 2005; Guerra et al, 2017). Several studies also point to the relevance of globalisation from industry viewpoints. Additional work emphasizes the general importance for engineers of knowing how to work with diversity, whether locally or internationally (Delaine et al, 2016)

Downey et al (2006, p.4) described global competence as the development of "knowledge, ability, and predisposition to work effectively with people who define problems differently than they do." Highlighted here is the importance of working with people who think differently and the ability to be open to "different ways of thinking, and different social values". (Katehi, 2005, p.152). Downey argues that this ability to work with difference has special significance for engineering education, and it is obviously of particular interest for questions of learning how to use diversity and how to work within a diverse workforce. As Page (2007) has illustrated, a diverse team can help not only with solving problems--a core engineering skill--but can also help to redefine the problem and come up with a highly innovative solution to this novel problem. Framing and reframing problems as a way of deepening an understanding of the problem is also suggested by Adams et al (2011). Working in diverse teams with varying problem-framing heuristics thus offers a major opportunity, but only to those that know how to use diversity. Livermore (2016) has suggested that there are four key competences necessary for successfully using diversity and so fostering an inclusive team. These are a) openness and curiosity towards other ways of seeing, b) knowledge about the similarities and differences between cultures, c) an effective strategy for dealing with challenges caused by cultural differences, d) an ability and willingness to adapt and change.

Communication skills are obviously very important here as well, including the mastery of multiple languages.

Interdisciplinarity

Interdisciplinary can be understood as a form of diversity. Engineering graduates need to think differently and deal with complicated disruptive technologies whilst understanding and accommodating the social elements of any future challenges. The Engineer of 2020, (NAE, 2004) calls for engineers to work within a multidisciplinary perspective, and to consider design from multiple perspectives. The concept of multi and interdisciplinary work is proposed by several authors as a key skill for any engineering graduate to develop in relation to sustainable development (Mulder et al, 2010; Richter and Paretti, 2009; Adams et al, 2011; Kovesi et al, 2018; Tejedor and Segalas, 2015; Svanstrom et al, 2008). One aspect of this is the idea that engineering graduates must focus not only on how to solve technical problems, but need to understand the socio-technical contexts of problems and solutions (NAE, 2008). Based upon a study of student work on interdisciplinary projects at the Michigan Technical University, Knowlton et al (2014) conclude that two major skills are a key factor to success: 1) the ability to communicate and to be understood by others outside of one's home discipline; and 2) the capacity to integrate and accommodate ideas from other frameworks within one's current manner of thinking.

Adapting to Change

Another recurring topic is the idea of constant change within the engineering profession (NAE, 2004; Katehi, 2005; Svanstrom et al, 2008). This leads to the idea that engineers will need to be committed to lifelong learning and so will need to develop a capacity to learn (Martinez-Mediano and Lord 2012). Educators should teach engineers to think critically rather than memorize formulae, in order that they can cope with rapid change. "We must teach methods and not solutions" (Katehi, 2005, p 154.) It is generally thought that a more useful skill than what they learn is the capacity to learn itself, sometimes described as learning to learn or active learning (Misseyanni et al 2016). This adaptability and openness to change will be required if we are to achieve sustainability, since it is clearly the case that much of the current technology is unsustainable and will need to be replaced with new and sustainable systems.

Creativity and Flexibility

Creativity has been defined by some as cognitive flexibility (Guilford 1967). In order for engineers to be able to solve complicated and wicked problems, they need to be creative, curious and imaginative (NAE, 2004; Katehi, 2005; Tejedor and Segalas, 2015). In order to achieve this, students need to acquire a demystified understanding of the creative process and to learn which habits and managerial practices best foster creativity (Sawyer, 2007). For instance, they must learn to improve their attention and mindfulness, so that they can come to see problems clearly (Langer, 1989). They must also learn how to cultivate a positive creative mindset within themselves and their teams (Sawyer, 2012). This overlaps with the skills involved in working in interdisciplinary teams have also been largely demonstrated to be a major stimulus to creativity (Livermore, 2016). Resnick (2018) has indicated that these skills, as well as an understanding of how to employ play and iteration in the creative process, can be integrated into engineering education via a play and making based curriculum.

Communication with diverse audiences

The idea that engineers must possess skills to deal with society as a whole is also reflected by The Engineer of 2020 project (NAE, 2004) which calls for graduates to have social and political acumen which will be needed to make changes in the world, a skill which Miller (2015) also holds in high regard. One key skill relevant for participating in political discussions is obviously communication, and specifically an understanding of how to translate the specialized terms of scientific and engineering knowledge into terms that make sense within the context of political discussions (Latour, 1999). Understanding the political and social stakes involved in engineering practices and also being able to predict and describe the social, ecological, and political consequences of projects is clearly also a relevant capacity in this regard.

Student awareness

Student awareness is not a skill, but as we have noted above it is vitally important for sustainability education. Awareness of sustainability as a problem is a prerequisite for desiring to acquire the skills for engineering sustainably. If students are not aware of the problems of sustainability, they are unlikely to be motivated to solve them, though it is also not true that being aware of a problem automatically implies that one cares enough to attempt to solve it. Of course, spreading awareness of the importance of these problems does generally increase the number of students interested in solving them.

DeCamara et al, (2017) have carried out a survey on 190 undergraduate engineering students in Spain. This study sought specifically to identify knowledge under the three pillars of sustainable development; environmental, social and economic. The study found that although there was a satisfactory knowledge about the environmental aspect of sustainable development, there were significant knowledge gaps in the economic and social domains.

Another study carried out on both engineering and non-engineering undergraduates understanding of sustainable development concluded that there were many similarities between both groups (Wilson and Kim, 2018). Interestingly, approximately 15% of students described sustainability in terms consistent with the Brundtland Commission definition (Brundtland, 1987). However, for those who did not, many of the students (53.7% of non-engineering students and 43.4% of engineering students) described sustainability as protection of the environment only, with only 3.1% of engineering students and 10.7% of non-engineering students specifically referring to a social or economic aspect of sustainability. Azapagic et al, (2005) concluded similarly that students' knowledge of sustainable development was lacking, in a worldwide survey of over 3000 students. He also found that there was little difference in the knowledge base of students from developed and developing countries included in the survey. In Istanbul, whilst there was an awareness amongst students about the environmental problems of the future, Eyuboglu et al, (2010) concluded that students had become aware of these issues through commercial media and not through formal education.

In Ireland, a study of final year engineering undergraduate students found similar results; that engineering students' knowledge in regard to sustainable development was inadequate (Nicolaou and Conlon, 2012 and Nicolaou et al, 2017). The results were compared with the findings of Azapagic et al (2005) study and showed the same knowledge gaps; in particular, with regard to social issues and SD legislation, policy and standards. However, students scored highly in SD knowledge in areas such as recycling and climate change, which Nicolaou and Conlon (2012) also conclude could be due to the media coverage of these issues.

Barriers

We have seen that sustainable development already forms a part of engineering education, and that a certain degree of consensus exists regarding the key skills necessary for forming the engineers of the future. In this section we turn to the question of barriers. What factors are likely to challenge attempts to train today's engineers to be the motors of tomorrow's sustainable development?

Bernstein et al, (2011) argue that one of the main barriers to teaching sustainable development is the crowded curriculum. Others argue that there is a lack of academic vision regarding the mission of the engineer and what influence they can have with regard to sustainable development (Mulder, 2010). This includes a resistance to change in general and to the time-consuming process of curriculum reform in particular. According to Mulder, in some quarters sustainable development is regarded as "an ill-defined world view, not as a discipline rooted in scientific knowledge" (Mulder, 2010, P.630). Jamison et al, (2014) suggest that there exist vastly differing conceptions of engineering, engineering competences and the role of engineering education. By failing to recognize the impact of these deep-seated conceptions, educators fail to bring about significant and meaningful reforms.

Peet et al, (2004) have approached the question of barriers more analytically, breaking down the sources of resistance into three categories: organizational culture, academic culture and engineering culture. Focusing on academic culture, they note that many engineering educators do not themselves feel competent to teach within a sustainable development framework, particularly if they were engineers themselves (Kovesi et al, 2018; Trad et al, 2018; Peet et al, 2004, Nicolau et al, 2017). Fitzpatrick (2018) has found that addressing the social and economic pillars of sustainability is particularly difficult for engineering educators, as they often feel as if the society and economy are outside of their disciplinary comfort zone. Likewise, it has been shown that many educators feel unprepared to teach diverse classrooms, let alone to integrate diversity thinking within their pedagogy (Dailey, 2015). This aspect is also noted by Trad et al, (2018) who in a study of 32 engineering academics concluded that the majority of academics interviewed, perceived sustainability as a technical subject, which was presumably taught by someone else in the curriculum who had specific expertise in sustainable development. Mulder (2013) puts forward a case for integrating sustainable development as a meta-context for engineering education. He proposes that in most engineering programmes, sustainable development is an aspect of engineering, rather than a central theme, comparable to the findings of Nicolaou et al, (2017). With this in mind, it is another subject which needs to be balanced with others and as such risks being downgraded in lieu of competing factors.

These findings highlight the importance of educating academia as to the range of articulations of sustainable development and how it can be integrated into the curriculum.

Conclusion

As we have seen, sustainable development is not only a major challenge for society, it is a major challenge for engineering education. Training the next generation of engineers to meet the demands of sustainable development is a major undertaking that will require a significant transformation of the current education system. In the preceding pages we have highlighted several areas that demand particular focus. As we have seen, increasing the diversity of our engineering schools poses both a major challenge and a significant opportunity. In order to make good on this opportunity, engineering schools need to become more attractive, not only appealing to those who have traditionally entered into engineering education but also drawing students from other social strata as well. One possibility for generating excitement and passion for engineering education is to help prospective students see the importance of engineering in the global project that is working towards sustainability. Yet in order to fully accomplish this, schools need to better understand how to successfully integrate sustainability training into the curriculum, not only in terms of spreading student awareness and motivation around collective problems and grand challenges, but also by clarifying the skills necessary for carrying out engineering projects sustainably and by developing pedagogical practices capable of successfully inculcating these skills in the coming generation of engineers.

References

Topic 1-2 - Sustainable development and diversity

Aigbe, Oladunni, “Diversity and Inclusion Foster Innovative Development in an Emerging Networked Society”, (2016). Available at: http://eprints.covenantuniversity.edu.ng/6645/1/icadi16pp133-138.pdf.

Aparakakankanange, Erika, Renetta Garrison Tull, “An AGEP program analysis: Minority graduate student diversity in STEM disciplines at three maryland universities.” International Conference on Interactive Collaborative Learning (ICL), 2014.

Apfelbaum, E. P., Phillips, K. W., & Richeson, J. A. “Rethinking the baseline in diversity research: Should we be explaining the effects of homogeneity?” *Perspectives on Psychological Science 9*, (2014): 235–244.

Bauman, Georgia, L. Leticia Tomas Bustillos, Estela Mara Bensimon, M. Christopher Brown II, and RoSusan D. Bartee, “Achieving Equitable Educational Outcomes with All Students: The Institution’s Roles and Responsibilities.” (2005).

Brewer, M. B., & Brown, R. J. Intergroup relations. In D. T. Gilbert & S. T. Fiske (Eds.), *The handbook of social psychology* (4th ed.), vol. 2, (1998): 554–594. New York: McGraw-Hill.

Carlile, P. “A pragmatic view of knowledge and boundaries: Boundary objects in new product development.” *Organization Science 13,* (2002): 442-455.

Cox, T. H., & Blake, S. “Managing cultural diversity: Implications for organizational competitiveness.” *Academy of Management Executive 5*, No. 3 (1991): 45-56.

Davis, Lance. “*Surmounting the Barriers: Ethnic Diversity in Engineering Education. A Workshop Report.* Washington”, DC: The National Academies Press. ed. (2014).

Delaine, D.A., D.N. Williams, R. Sigamoney and R.G. Tull, “Global Diversity and Inclusion in Engineering Education: Developing Platforms toward Global Alignment International” *Journal of Engineering Pedagogy 6*, No 1 (2016): 56-71.

D’Iribarne, P. “La legitimite de l’entreprise comme acteur ethique aux Etats-Unis et en France [The legitimacy of the enterprise as an ethical actor in the United States and France].” *Revue Francaise de Gestion [French Review of Management] 140*, No. 28 (2002): 23-39.

Edmondson, Amy, Jean-François Harvey. “Cross-boundary teaming for innovation: Integrating research on teams and knowledge in organizations”, *Human Resource Management Review 28*, No. 4 (2018): 347-360.

Erhart, K. H., & Ziegert, J. C. “Why are individuals attracted to organizations?” *Journal of Management, 31*, (2005): 901-918.

Everenden, *The Natural Alien: Humankind and Environment*, (1987) University of Toronto Press, Toronto.

Fisher, T. A. “Pathways to Educational Inclusiveness.” *Educational Researcher 36, No.* 2 (2007): 103–107.

Galinsky, Adam D. Andrew R. Todd, Astrid C. Homan, Katherine W. Phillips, Evan P. Apfelbaum, Stacey J. Sasaki, Jennifer A. Richeson, “Maximizing the Gains and Minimizing the Pains of Diversity: A Policy Perspective*”, Perspectives on Psychological Science 10*, No. 6 (2015): 742–748.

Grimson, Jane and Rougheen, Caroline, "*Diversity in engineering: tinkering, tailoring, transforming?*", eds. Hyldgaaard Christensen, Bernard Delahousse and Martin Meganck in Engineering in Context, Denmark, Academica, (2009): 197 – 220.

Groysberg, Boris and Katherine Connolly, "Great Leaders Who Make the Mix Work." *Harvard Business Review 91*, No. 9 (2013): 68-76.

Harkavy, Ira, Cantor, Nancy, and Burnett, Myra, "Realizing STEM Equity and Diversity through Higher Education Community Engagement." (2015), Available at: https://www.nettercenter.upenn.edu/sites/default/files/Realizing_STEM_Equity_Through_Higher_Education_Community_Engagement_Final_Report_2015.pdf.

Harrison, D.A., Klein K.J. "What's the difference? Diversity constructs as separation, variety, or disparity in organizations." *Academy of Management Review* 32, (2007): 1199-1228.

Henze, R., Katz, A., Norte, E., Sather, S. E, & Walker, E. "Leading for Diversity: How School Leaders Promote Positive Interethnic Relations." UC Berkeley: Center for Research on Education, Diversity and Excellence, (2001).

Hornsey, M. J., & Imani, A. "Criticizing groups from the inside and the outside: An identity perspective on the intergroup sensitivity effect." *Personality and Social Psychology Bulletin 30*, No. 3 (2004): 65–383.

Jackson, S. E., & Joshi, A. "Diversity in social context: A multi-attribute, multilevel analysis of team diversity and sales performance." *Journal of Organizational Behavior 25*, (2004): 675-702.

Jackson, S. E. K. E. May, and K. Whitney, *Understanding the Dynamics of Diversity in Decision-Making Teams*, in Team Effectiveness and Decision Making in Organizations, ed. R. A. Guzzo and E. Salas (San Francisco: Jossey-Bass), (1995): 204–261.

James, Hansen, Rioux Janie, and Twomlow Stephen. "Urgent action to combat climate change and its impacts (SDG 13): transforming agriculture and food systems." *Current Opinion in environmental Sustainability* 34 (2018): 13-20.

Janis, I. "*A First Look at Communication Theory*" Groupthink. In E. Griffin (Ed.) New York: McGrawHill. (1991): 35 - 246.

Klein, K. J., & Harrison, D. A. "On the diversity of diversity: Tidy logic, messier realities." *The Academy of Management Perspectives 21*, No. 4 (2007): 26–33.

Kochan, T., Bezrukova, K., Ely, R. J., Jackson, S., Joshi, A., Jehn, K. A., . . . Thomas, D. "The effects of diversity on business performance: Report of the diversity research network." *Human Resource Management 42*, No. 1 (2003): 3-21.

Lhong, L. and Page, S. " Problem Solving by Heterogeneous Agents." *Journal of Economic Theory 97*, (2001): 123-163.

Liao, Lin, Le Luo, Qingliang Tang, "Gender diversity, board independence, environmental committee and greenhouse gas disclosure." *The British Accounting Review 47*, No. 4 (2015): 409-424.

Massey, D. S., C. Z. Charles, G. F. Lundy, and M. J. Fisher. *The source of the river: The social origins of freshmen at America's selective colleges and universities.* Princeton, NJ: Princeton University Press, 2003.

Milem, Jeffrey F., Mitchell J. Chang, and Anthony Lising Antonio. *Making diversity work on campus: A research-based perspective*. Washington, DC: Association American Colleges and Universities, 2005.

Mitchell, Rebecca, Vicki Parker & Michelle Giles, "Open-mindedness in diverse team performance: investigating a three-way interaction." *The International Journal of Human Resource Management 23*, No. 17 (2012): 3652-3672.

Mor Barak, Michalle, E. “*Managing diversity: Toward a globally inclusive workplace*.” Sage Publications, 2016.

Mor Barak and Michàlle E. "Inclusion is the key to diversity management, but what is inclusion?." *Human Service Organizations: Management, Leadership & Governance* 39, no. 2 (2015): 83-88.

Nadeem, Muhammd, Zaman, Rashid, Saleem, Irfan “Boardroom gender diversity and corporate sustainability practices: Evidence from Australian Securities Exchange listed firms.” *Journal of Cleaner Production 149*, (2017): 874-885.

Nemeth, Charlan and Joel Wachtler, “Creative problem solving as a result of majority vs minority influence?” *European Journal of Social Psychology 13*, (1983): 45-55.

Nilsson, Åsa Wikberg, and Marcus Jahnke. "Tactics for Norm-Creative Innovation." *She Ji: The Journal of Design, Economics, and Innovation* 4.4 (2018): 375-391.

Nishii, L. H. “The benefits of climate for inclusion for gender-diverse groups.” *Academy of Management Journal 56*, (2013): 1754–1774.

Olsen, Jesse E., et al "Gender diversity programs, perceived potential for advancement, and organizational attractiveness: An empirical examination of women in the United States and France." *Group & Organization Management 41*, No. 3 (2016): 271-309.

Packer, Dominic J., Christopher TH Miners, and Nick D. Ungson. "Benefiting from diversity: How groups’ coordinating mechanisms affect leadership opportunities for marginalized individuals." *Journal of Social Issues* 74, No.1 (2018): 56-74.

Phelps, Edmund S. *Mass flourishing: How grassroots innovation created jobs, challenge, and change*. Princeton University Press, 2013.

Riordan, C. M. & Shore, L. M. “Demographic diversity and employee attitude: An empirical examination of relational demography within work units.” *Journal of Applied Psychology 82*, (1997): 342-358.

Ruggs, Enrica, and Michelle Hebl. "Literature overview: Diversity, inclusion, and cultural awareness for classroom and outreach education." *Apply research to practice (ARP) resources. Retrieved from https://www. engr. psu. edu/awe/ARPAbstracts/DiversityInclusion/ARP_ DiversityInclusionCulturalAwareness_Overview. Pdf* (2012).

Russell, Martha G. Nataliya V. Smorodinskaya, “Leveraging complexity for ecosystemic innovation.” *Technological Forecasting and Social Change 136*, (2018): 114-131.

Sawyer, Keith. *Group genius: The creative power of collaboration*. Basic Books, 2017.

Schofield, Janet Ward, “*Maximizing the Benefits of Student Diversity: Lessons from School Desegregation Research.”* In: Orfield, Gary, Ed., Diversity Challenged: Evidence on the Impact of Affirmative Action. Cambridge, Harvard Education Publishing Group. (2011): 99-109.

Shore, L. M., Randel, A. E., Chung, B. G., Dean, M. A., Holcombe Ehrhart, K., & Singh, G. “Inclusion and diversity in work groups: A review and model for future research.” *Journal of Management 37*, (2011): 1262–1289.

Slavin, R. E. “*Cooperative learning and intergroup relations.*” In J. A. Banks & C. A. McGee Banks (Eds.), Handbook of research on multicultural education New York: Simon & Schuster Macmillan (1995): 628-634.

Smith, A. “Translating sustainabilities between green niches and socio-technical regimes.” *Technology Analysis & Strategic Management 19*, (2007): 427–450.

Smith, A., Ely, A., Fressoli, M., Abrol, D. & Arond, E. *Grassroots innovation movements*. Routledge, 2016.

Van Knippenberg, D. J., J. N. “Mell Past, present, and potential future of team diversity research: From compositional diversity to emergent diversity.” *Organizational Behavior and Human Decision Processes, 136*, (2016): 135-145.

Wang, Cynthia S., et al "The cultural boundaries of perspective-taking: When and why perspective-taking reduces stereotyping." *Personality and Social Psychology Bulletin* 44, No. 6 (2018): 928-943.

Woodcock, Stuart and Lisa Marks Woolfson. "Are leaders leading the way with inclusion? Teachers' perceptions of systemic support and barriers towards inclusion." *International Journal of Educational Research* 93 (2019): 232-242.

Topic 3 – The role of Engineers in achieving SDGs

Alhaddi, Hanan. "Triple bottom line and sustainability: A literature review." *Business and Management Studies* 1, No. 2 (2015): 6-10.

Al Nuaimi, Eiman, et al "Applications of big data to smart cities." *Journal of Internet Services and Applications* 6, No. 1 (2015): 1-25.

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.

ASEE (2016) https://webcache.googleusercontent.com/search?q=cache:LIN_2QFWowIJ:https://peer.asee.org/engineering-the-un-post-2015-sustainable-development-goals.pdf+&cd=2&hl=en&ct=clnk&gl=fr.

Batty, Michael, et al "Smart cities of the future." *The European Physical Journal Special Topics 214*, No. 1 (2012): 481-518.

Bibri, Simon Elias, and John Krogstie. "Smart sustainable cities of the future: An extensive interdisciplinary literature review." *Sustainable Cities and Society 31* (2017): 183-212.

Brynjolfsson, Erik and McAfee, Andrew, “*Race Against The Machine: How the Digital Revolution is Accelerating Innovation, Driving Productivity, and Irreversibly Transforming Employment and the Economy*.” Digital Frontier Press, 2011.

Campbell, Scott. "Green cities, growing cities, just cities? Urban planning and the contradictions of sustainable development." *Journal of the American Planning Association* 62.3 (1996): 296-312.

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

Clifford, Katie L., and Muhammad H. Zaman. "Engineering, global health, and inclusive innovation: focus on partnership, system strengthening, and local impact for SDGs." *Global health action 9*, No. 1 (2016): 30175.

Cohen, S. *The Sustainable City*. New York: Columbia University Press, 2017.

Comer, A. "The engineer's role in the future city”, Available at: https://www.ice.org.uk/news-and-insight/ice-thinks/growing-cities-and-building-resilience/the-engineers-role-in-the-future-city, 2016.

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

Cruickshank, H. J., and Fenner, R.A. "The evolving role of engineers: towards sustainable development of the built environment." *Journal of International Development: The Journal of the Development Studies Association 19*, No.1 (2007): 111-121.

Diamond, Jared. *Collapse: How societies choose to fail or succeed*. Penguin, 2005.

Dodds, Richard, and Roger Venables. *Engineering for sustainable development: Guiding principles.* Royal Academy of Engineering*, London* (2005).

EAPN report (2015). Available at: http://energyaccess.org/wp-content/uploads/2015/07/EAPN-Towards-Achieving-Universal-Energy-Access-by-2030.pdf

Ehrenfeld, J. R. "The roots of sustainability." *MIT Sloan Management Review 46*, No. 2 (2005): 23-25.

Elkington, John, and Ian H. Rowlands. "Cannibals with forks: the triple bottom line of 21st century business." *Alternatives Journal* 25, No. 4 (1999): 1-42.

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

Fekete, Balázs M., and János J. Bogárdi. "Role of engineering in sustainable water management." *Earth Perspectives 2*, No. 1 (2015): 2.

Gauvreau, Paul. "Sustainable education for bridge engineers." *Journal of Traffic and Transportation Engineering (English Edition) 5*, No. 6 (2018): 510-519.

Giovannoni, Elena, and Giacomo Fabietti. *What is sustainability? A review of the concept and its applications*. Integrated reporting. Springer, Cham, (2013): 21-40.

Goodall, Chris. *Sustainability: All that matters*. Hodder & Stoughton, 2012.

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.

Herrmann A.W. "Sustainable Urban Renewal: Engineers' Role in Changing the Built Environment in Livable Cities of the Future." Proceedings of a Symposium Honoring the Legacy of George Bugliarello, 2014.

Jackson, Tim. *Prosperity without growth: foundations for the economy of tomorrow*. Routledge, 2016.

Jessell, Mark, et al "New models for geoscience higher education in West Africa." *Journal of African Earth Sciences 148* (2018): 99-108.

Karlsson, Rasmus. "Three metaphors for sustainability in the Anthropocene." *The Anthropocene Review 3*, No. 1 (2016): 23-32.

Kopnina, Helen. "Metaphors of nature and economic development: Critical education for sustainable business." *Sustainability 6*, No. 11 (2014): 7496-7513.

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

Lazzarini, Boris, Agustí Pérez-Foguet, and Alejandra Boni. "Key characteristics of academics promoting Sustainable Human Development within engineering studies." *Journal of Cleaner Production 188*, (2018): 237-252.

Lozano, R. "Envisioning sustainability three-dimensionally." *Journal of Cleaner Production 16*, (2008): 1838–1846.

Mallett, Alexandra. "Beyond frontier technologies, expert knowledge and money: New parameters for innovation and energy systems change." *Energy Research & Social Science 39* (2018): 122-129.

Miller, Riel, Roberto Poli, and Pierre Rossel. "The discipline of anticipation: Foundations for futures literacy." *Transforming the Future (Open Access)*. Routledge (2018): 75-89.

Minnock, O., “Interview with Olivia Minnock”, Available at: https://www.energydigitalcom/sustainability/institute-civil-engineers-uniting-engineering-sustainable-development, 2018.

Mora, Higinio, et al "An education-based approach for enabling the sustainable development gear." *Computers in Human Behavior* (2018).

Mulder, Karel F. "Strategic competences for concrete action towards sustainability: An oxymoron? Engineering education for a sustainable future." *Renewable and Sustainable Energy Reviews 68* (2017): 1106-1111.

Neumayer, Eric. *Weak versus strong sustainability: exploring the limits of two opposing paradigms*. Edward Elgar Publishing, 2003.

Norton, Bryan G. *Sustainability: A philosophy of adaptive ecosystem management*. University of Chicago Press, 2005.

Portney, Kent E. *Sustainability*. MIT Press, 2015.

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).

Ross, Alec*, The Industries of the Future*, New York: Simon & Schuster, 2016.

Sachs, J. *The Age of Sustainable Development*, New York: Columbia University Press, 2015.

SDSN (Sustainable Development Solution Network), “Getting Started with the SDG’s in Cities: A Guide for Stakeholders», Available at: http://unsdsn.org/wp-content/uploads/2016/07/9.1.8.-Cities-SDG-Guide.pdf (2016).

Shellenberger, Michael, and Ted Nordhaus, eds. *Love your monsters: postenvironmentalism and the Anthropocene*. Breakthrough Institute, 2011.

Steffen, Will, et al "Planetary boundaries: Guiding human development on a changing planet." *Science* 347.6223 (2015): 1259855.

Vandemoortele, Jan. "From simple-minded MDGs to muddle-headed SDGs." *Development Studies Research* 5, No. 1 (2018): 83-89.

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.

Xiao, Wen, et al "Geoinformatics for the conservation and promotion of cultural heritage in support of the UN Sustainable Development Goals." *ISPRS journal of photogrammetry and remote* sensing 142 (2018): 389-406.

Young, R. F. and Lieberknecht, K. "From smart cities to wise cities: ecological wisdom as a basis for sustainable urban development." *Journal of Environmental Planning and Management* (2018): 1-18.

Zhang, Qiong, et al "More than Target 6.3: A Systems Approach to Rethinking Sustainable Development Goals in a Resource-Scarce World." *Engineering 2*, No. 4 (2016): 481-489.

Topic 4 – Attractiveness of Engineering Education

Alika, H. “Career choice in engineering: The influence of peers and parents implication for counselling.” *College Student Journal 46*, No. 3 (2012): 537-542.

Amabile, T.M., Hennessey, B. A., "Reward, Intrinsic Motivation, and Creativity." *American Psychologist 53*, no. 6 (1998): 674–675.

Amelink, C. T. *Overview: Mentoring and Women in Engineering*. In SWE-AWE-CASEE ARP Resources: Mentoring and Women in Engineering, Assessing Women (and Men) in Engineering (AWE) project: Literature Overviews, USA (2004).

Arlett, C., Lamb, F., Dales, R., Willis, L., & Hurdle, E. “Meeting the needs of industry: the drivers for change in engineering education.” *Engineering Education* 5, No. 2 (2010): 18-25.

ATTRACT. ”Attract project final rapport – Enhancing the attractiveness of Studies in Science and Technology” (2012): 1-246.

Azapagic, A., Perdan, S. and Shallcross, D. “How much do engineering students know about sustainable development? The findings of an international survey and possible implications for the engineering curriculum.” *European Journal of Engineering Education 30*, No. 1 (2005): 1-19.

Banerjee Pallavi, Amitava, Lamb, Stephen (Reviewing Editor). “ A systematic review of factors linked to poor academic performance of disadvantaged students in science and maths in schools”, *Cogent Education* 3, No. 1 (2016) DOI: 10.1080/2331186X.2016.1178441

Becker, F. S. “Why don't young people want to become engineers? Rational reasons for disappointing decisions.” *European Journal of Engineering Education 35*, No. 4, (2010):349-366.

Brandt CB. “Discursive geographies in science: Space, identity, and scientific discourse among indigenous women in higher education.” *Cultural Studies in Science.* Education 3 (2008):703–730.

Brown B. “Discursive identity: Assimilation into the culture of science and its implications for minority students.” *Journal of Research in Science Teaching* 41, No. 8 (2004):810–834.

Carleone HB, Johnson A. “Understanding the science experiences of successful women of color: Science identity as an analytic lens.” *Journal of Research in Science Teaching 44*, No. 8 (2007):1187–1218.

Carnasciali, M. I., Thompson, A. E., & Thomas, T. J. “Factors influencing students’ choice of engineering major.” In Proc. 120th ASEE Annu. Conf. Expo (2013):31-36.

Cech EA, Waidzunas TJ. “Navigating the heteronormativity of engineering: The experiences of lesbian, gay, and bisexual students.” *Engineering Studies 1*, No. 1 (2011):1–24.

Cheryan S, Plaut VC, Davies P, Steele CM. “Ambivalent belonging: How stereotypical environments impact gender participation in computer science.” *Journal of Personality and Social Psychology 97* (2009):1045–1060.

Dai T, Cromley JG. “Changes in implicit theories of ability in biology and dropout from STEM majors: A latent growth curve approach.” *Contemporary Educational Psychology 39*, No. 3 (2014):233–247.

Duderstadt, J. J. *Engineering for a changing world. In Holistic engineering education*, Springer, (2010):17-35, New York, NY.

EC. “Young people and science: analytical report”, Flash Barometer 239, European Commission: Brussels, (2008):1-206. Available at: http://ec.europa.eu/commfrontoffice/publicopinion/flash/fl_239_en.pdf.

Filipkowski, A. “Attractiveness of engineering education in ICT dominated world.” In Proceedings of the SEFI 2009 Annual Conference, (2009).

Godwin, A., Klotz, L., Hazari, Z., & Potvin, G. “Sustainability goals of students underrepresented in engineering: An intersectional study.” *International Journal of Engineering Education 32*, No. 4 (2016):1742-1748.

Hanson, M., Engström, E., Kairamo, A., & Varano, M. “Enhance the attractiveness of studies in science and technology.” In Joint International IGIP-SEFI Annual Conference, IGIP-SEFI, Trnava, Slovakia, (2010, September).

Hewlett SA, Luce CB, Servon LJ. *The Athena Factor: Reversing the Brain Drain in Science, Engineering, and Technology.* Watertown, MA: Harvard Business School, (2008).

Hrad, J. and Zeman, T. “Increasing the attractiveness of engineering education in the area of electronic communications.” *Elektronika ir Elektrotechnika 102*, No. 6 (2010):79-82.

Johnson, W. C., & Jones, R. C. “Declining interest in engineering studies at a time of increased business need.” Accreditation Board for Engineering and Technology, (2006).

Katzis, K., Dimopoulos, C., Meletiou-Mavrotheris, M., & Lasica, I. E. “Engineering Attractiveness in the European Educational Environment: Can Distance Education Approaches Make a Difference?” *Education Sciences 8*, No. 1 (2018):1-16.

Kövesi, K., & Schrey-Niemenmaa, K. “Attractiveness of Engineering Profession in Europe”, In Proceedings of the 45th SEFI conference, (2017).

Lee LA, Hansen LE, Wilson DM. « The Impact of Affective and Relational Factors on Classroom Experience and Career Outlook among First-year Engineering Undergraduates.” San Diego, CA: 2006. (Presentation at the Frontiers in Education 36th Annual Conference, Oct. 27–31).

Malcom S, Feder M, editors, *Committee on Barriers and Opportunities in Completing 2-Year and 4-Year STEM Degrees; Board on Science Education; Division of Behavioral and Social Sciences and Education*; Board on Higher Education and Workforce; Policy and Global Affairs; National Academy of Engineering; National Academies of Sciences, Engineering, and Medicine; Washington (DC): National Academies Press (US), (2016).

Male, S., & King, R. “Improving industry engagement in engineering degrees.” In 25th Annual Conference of the Australasian Association for Engineering Education: Engineering the Knowledge Economy: Collaboration, Engagement & Employability (p. 363). School of Engineering & Advanced Technology, Massey University, (2014).

Matusovich, H. M., R.A. Streveler, and R.L. Miller. “Why do students choose engineering? A qualitative, longitudinal investigation of students’ motivational values.” *Journal of Engineering Education 99,* No. 4, (2010).

Miller, M. J., Lent, R. W., Lim, R. H., Hui, K., Martin, H. M., Jezzi, M. M., ... & Wilkins, G. “Pursuing and adjusting to engineering majors: A qualitative analysis.” *Journal of Career Assessment* 23, No. 1 (2015): 48-63.

National Academy of Sciences, National Academy of Engineering, and Institute of Medicine Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads Committee on Underrepresented Groups and the Expansion of the Science and Engineering Workforce Pipeline; Committee on Science, Engineering, and Public Policy; Policy and Global Affairs, (2010).

Nicolaou, I., & Conlon, E. “What do final year engineering students know about sustainable development?” *European Journal of Engineering Education 37*, No. 3 (2012): 267-277.

Olitsky S. “Facilitating identity formation, group membership, and learning in science classrooms: What can be learned from out-of-field teaching in an urban school.” *Science Education 91*, No. 2 (2006): 201–221.

Pink, Daniel H. Drive, *The Surprising Truth About What Motivates*. Us. Riverhead Books, New York. (2009).

Roychoudhury, A., Tippins, D. J. and Nichols, S. E. “Gender-inclusive science teaching: A feminist-constructivist approach.” *Journal of Research of Science Teaching 32*, (1995):897-924. DOI: 10.1002/tea.3660320904.

Seymour, E., Hunter, A. B., Laursen, S. L., & Deantoni, T. “Establishing the benefits of research experiences for undergraduates in the sciences: First findings from a three-year study.” *Science Education 88*, No. 4 (2004):493–534.

Sithole, Alec, Edward T. Chiyaka, Peter McCarthy , Davison M. Mupinga , Brian K. Bucklein & Joachim Kibirige “Student Attraction, Persistence and Retention in STEM Programs: Successes and Continuing Challenges.” *Higher Education Studies 7*, No. 1 (2017):46-59.

Sjøberg, S., Schreiner, C., Bauer, M., Allum, N., & Shukla, R. “*The next generation of citizens: attitudes to science among youngsters. The culture of science–How does the public relate to science across the globe*.” (2010).

Schrey-Niemenmaa, K., & Jones, M. E. “Attractiveness in Engineering Education Is all as it seems.” In Proceedings of the SEFI 2011 Annual Conference, Lisbon, (2011).

Segalàs, J., Ferrer-Balas, D., & Mulder, K. F. “Conceptual maps: measuring learning processes of engineering students concerning sustainable development.” *European Journal of Engineering Education 33*, No. 3 (2008): 297-306.

Tjoa, A. Min, and Simon Tjoa. "The role of ICT to achieve the UN Sustainable Development Goals (SDG)." IFIP World Information Technology Forum. Springer, Cham, (2016).

Woolnough, B. E. “Factors affecting students' choice of science and engineering.” *International Journal of Science Education 16*, No. 6 (1994): 659-676.

Topic 5 – Future skills and competencies

ABET, *Accrediting Engineering Programs, Effective for Reviews During the 2015-2016 Accreditation Cycle*, ABET, USA (2014)

Adams, Robin S., Shanna R. Daly, Llewellyn M. Mann, and Gloria Dall'Alba. "Being a professional: Three lenses into design thinking, acting, and being." *Design Studies* 32, no. 6 (2011): 588-607.

AHEP, *The Accreditation of Higher Education Programmes UK Standard for Professional Engineering Competence*, Engineering Council, UK (2016).

ASEE, *Transforming Undergraduate Education in Engineering Phase I: Synthesizing and Integrating Industry Perspectives*, ASEE, Arlington (2013)

ASEE, *“The attributes of a global Engineer Project,” Global Engineering Deans council,* ASEE, USA (2015).

Azapagic, Adisa, Slobodan Perdan, and David Shallcross. "How much do engineering students know about sustainable development? The findings of an international survey and possible implications for the engineering curriculum." *European Journal of Engineering Education* 30, no. 1 (2005): 1-19.

Azapagic, Adisa, Slobodan Perdan, and Roland Clift, eds. *Sustainable development in practice: case studies for engineers and scientists*. John Wiley & Sons, 2004.

Bernstein, William Zev, Devarajan Ramanujan, Monica F. Cox, Fu Zhao, John W. Sutherland, and Karthik Ramani. "Implementing design critique for teaching sustainable concept generation." In DS 68-8: Proceedings of the 18th International Conference on Engineering Design (ICED 11), Impacting Society through Engineering Design, Vol. 8: Design Education, Lyngby/Copenhagen, Denmark, 15.-19.08. 2011. 2011.

“Barcelona Declaration”, Settled at the 2nd International Conference of Engineering Education for Sustainable Development. Accessed December 28, 2018. https://eesd2018.org/conference/the-barcelona-declaration/.

Brundiers, Katja, Arnim Wiek, and Charles L. Redman. "Real-world learning opportunities in sustainability: from classroom into the real world." International Journal of Sustainability in Higher Education 11, no. 4 (2010): 308-324.

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

Byrne, Edmond P., Cheryl J. Desha, John J. Fitzpatrick, and Karlson Hargroves. "Engineering education for sustainable development: A review of international progress." International Symposium for Engineering Education, 2010.

Cedefop. *Terminology of European education and training policy – A selection of 130 key terms.* Luxembourg*:* (2014)

CTI, *Accreditation Criteria, Guidelines and Procedures*. Available from: https://www.cti-commission.fr/wp-content/uploads/2017/12/cti-references-guidelines-2018_web_201712.pdf. Accessed 05 December, 2018.

Dailey, Debbie, Gary Bunn, and Alicia Cotabish. "Answering the call to improve STEM education: A stem teacher preparation program." *Journal of the National Association for Alternative Certification* 10, no. 2 (2015): 3-16.

Davidson, Cliff I., Chris T. Hendrickson, H. Scott Matthews, Michael W. Bridges, David T. Allen, Cynthia F. Murphy, Braden R. Allenby, John C. Crittenden, and Sharon Austin. "Preparing future engineers for challenges of the 21st century: Sustainable engineering." Journal of cleaner production 18, no. 7 (2010): 698-701.

Delaine, David Antoine, Renetta Tull, Rovani Sigamoney, and Darryl N. Williams. "Global diversity and inclusion in engineering education: Developing platforms toward global alignment." *International Journal of Engineering Pedagogy (iJEP)* 6, no. 1 (2016): 56-71.

DeCamara, Estibaliz Saez, Naia Gastelu, Alexander Lopez-Urionbarrenechea, Izaskun Ortiz de Zarate, Gaizka Insunza, Patix Ruiz de Arbulo “Engineering Students knowledge and understanding of sustainable development” in 1st International Conference on Engineering Education for the XXI Century–New competences on Engineering Education in the area of sustainability and university social responsibility. (2017). Available: https://addi.ehu.es/bitstream/handle/10810/25803/UCR00176423.pdf?sequence=1&isAllowed=y [accessed 5th December 2018]

Downey, Gary Lee, Juan C. Lucena, Barbara M. Moskal, Rosamond Parkhurst, Thomas Bigley, Chris Hays, Brent K. Jesiek et al "The globally competent engineer: Working effectively with people who define problems differently." *Journal of Engineering Education* 95, no. 2 (2006): 107-122.

Engineers Ireland, *Accreditation Criteria for Professional Titles*, Available from http://www.engineersireland.ie/EngineersIreland. Accessed 4 January 2015.

Engineers Ireland, *Industry 4.0 – Manufacturing Industry in Ireland: Engineers Ireland Policy statement.* Available: http://engineersireland.ie/EngineersIreland/media/SiteMedia/communications/publications/Engineers-Ireland-Industry-40-Policy-Statement.pdf?ext=.pdf. Accessed 17 February, 2019.

Eyuboglu, O. Uslu, and M. D. Oz. "Attitudes of University Students Towards Economic and Sustainable Development, in Istanbul." International Review of Business Research Papers6, no. 3 (2010): 123-128. Godwin, Allison, Leidy Klotz, Zahra Hazari, and Geoff Potvin. "Sustainability Goals of Students Underrepresented in Engineering: An Intersectional Study." International Journal of Engineering Education 32, no. 4 (2016): 1742-1748.

Guerra, Aida, Ron Ulseth, Bart Jonhson, and Anette Kolmos. "Engineering grand challenges and the attributes of the global engineer: a literature review." In Proceedings of the 45th SEFI Annual Conference, pp. 1222-1235. SEFI: European Association for Engineering Education, 2017.

Guilford, Joy P. "Creativity: Yesterday, today and tomorrow." *The Journal of Creative Behavior* 1, no. 1 (1967): 3-14.

Haase, S. "Engineering students' sustainability approaches." *European Journal of Engineering Education 39*, no. 3 (2014): 247-271.

Hanning, Andreas, Anna Priem Abelsson, Ulrika Lundqvist, and Magdalena Svanström. "Are we educating engineers for sustainability? Comparison between obtained competences and Swedish industry's needs." International Journal of Sustainability in Higher Education 13, no. 3 (2012): 305-320.

Holzer, Adrian, Isabelle Voneche Cardia, Samuel Bendahan, Alexis Berne, Luca Bragazza, Antonin Danalet, Ambrogio Fasoli et al "Increasing the Perspectives of Engineering Undergraduates on Societal Issues through an Interdisciplinary Program." *International Journal of Engineering Education 32*, no. ARTICLE (2016).

IEA, *Graduate Attributes and Professional Competencies: Version 3*, Available: http://www.ieagreements.org/assets/Uploads/Documents/Policy/Graduate-Attributes-and-Professional-Competencies.pdf. Accessed 17 February 2019.

Jamison, Andrew, Anette Kolmos, and Jette Egelund Holgaard. "Hybrid learning: An integrative approach to engineering education." *Journal of Engineering Education* 103, no. 2 (2014): 253-273.

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

Kövesi, Klara, Stéphane Flament, Gérald Majou de La Débutrie, Carine Sonntag, and Bluteau Hélène. "'Transdisciplinary Approach to Sustainable Innovation and Entrepreneurship Education'pp952-959 of the proceedings." In *Annual Conference of the European Society for Engineering Education, SEFI 2018*. 2018.

Knowlton, Jessie, Kathleen Halvorsen, Robert Handler, and Michael O'Rourke. "Teaching interdisciplinary sustainability science teamwork skills to graduate students using in-person and web-based interactions." *Sustainability 6*, no. 12 (2014): 9428-9440.

Langer, Ellen, *Mindfulness*, New York: Da Capo, 1989.

Latour, Bruno. (1999) *Politiques de la nature. Comment faire entrer les sciences en démocratie*. Paris, La Découverte.

Markes, Imren. "A review of literature on employability skill needs in engineering." *European Journal of Engineering Education 31*, no. 6 (2006): 637-650.

Martínez-Mediano, Catalina, and Susan M. Lord. "Lifelong learning competencies program for engineers." *International Journal of Engineering Education 28*, no. 1 (2012): 130.

Miller, Richard K. "Why the hard science of engineering is no longer enough to meet the 21st century challenges." *Olin College of Engineering* (2015). Retrieved January 2nd, 2016 from http://www.olin.edu/sites/default/files/rebalancing_engineering_education_may_15.pdf

Misseyanni, Anastasia, Christina Marouli, Paraskevi Papadopoulou, Miltiadis Lytras, and Maria Teresa Gastardo. "Stories of active learning in STEM: Lessons for STEM education." In *Proceedings of the International Conference The Future of Education,*, p. 232À236. 2016.

Mulder, Karel F., Jordi Segalas-Coral, and Didac Ferrer-Balas. "Educating engineers for/in sustainable development? What we knew, what we learned, and what we should learn." Thermal science 14, no. 3 (2010): 625-639.

Mulder, Karel, Cheryl Desha, and Karlson' Charlie Hargroves. "Sustainable development as a meta-context for engineering education." Journal of Sustainable Development of Energy, Water and Environment Systems 1, no. 4 (2013): 304-310.

NAE, *The engineer of 2020: Visions of engineering in the new century.* Washington, DC: National Academies Press (2004)

NAE, *Grand Challenges for Engineering*. Washington DC, National Academics Press (2008)

Nasr, Karim J. "Towards a converged and global set of competencies for graduates of engineering programs in a globalization-governed world." *Impact of Globalization On Engineering Education* 15 (2014): 15.

Nicolaou, Iacovos, and Eddie Conlon. "What do final year engineering students know about sustainable development*?." European Journal of Engineering Education 37*, no. 3 (2012): 267-277.

Nicolaou, Iacovos, Eddie Conlon, and Brian Bowe. "Into the Deep: The Role of Paradigms in Understanding Engineering Education for Sustainable Development." (2017).

Peet, D-J., Karel F. Mulder, and Arianne Bijma. "Integrating SD into engineering courses at the Delft University of Technology: The individual interaction method." International Journal of Sustainability in Higher Education 5, no. 3 (2004): 278-288.

Polastri, Patricia, and Todd E. Alberts. "Developing a globalized and sustainable mindset in 21st century engineering students." *Impact of Globalization On Engineering Education 83* (2014): 83.

Resnick, Mitchel, and Ken Robinson. *Lifelong kindergarten: Cultivating creativity through projects, passion, peers, and play*. MIT Press, 2017.

Richter, David M., and Marie C. Paretti. "Identifying barriers to and outcomes of interdisciplinarity in the engineering classroom." European Journal of Engineering Education 34, no. 1 (2009): 29-45.

Sánchez Carracedo, Fermín, Jorge Segalàs Coral, Eva María Vidal López, Carme Martín Escofet, Joan Climent Vilaró, David López Álvarez, and José M. Cabré Garcia. "Improving engineering educators' sustainability competencies by using competency maps: The EDINSOST project." *International journal of engineering education* 34, no. 5 (2018): 1527-1537.

Schmidt, K., R. Lee, W. Lorenz, P. Singh, and M. McGrail. "Use of STEEP Framework as basis for Sustainable Engineering Education." In *The 7 th International Conference on Engineering Education for Sustainable Development, Vancouver, Canada, June*, pp. 9-12. 2015.

Segalàs, Jordi, Dídac Ferrer-Balas, Magdalena Svanström, Ulrika Lundqvist, and Karel F. Mulder. "What has to be learnt for sustainability? A comparison of bachelor engineering education competences at three European universities." Sustainability Science 4, no. 1 (2009a): 17.

Segalàs, J., D. Ferrer-Balas, and K. F. Mulder. "Introducing sustainable development in engineering education: competences, pedagogy and curriculum." In *Proc. of the 37 th Annual Conference of the Society for Engineering Education (SEFI), Rotterdam, The Netherlands*. 2009.

Streiner, Scott, Anita Vila-Parrish and Gregg Warnick. "An exploratory study of global competencies considered by multinational companies: A hiring perspective." International Journal of Engineering Education 31, no. 5 (2015): 1239-1254.

Svanström, Magdalena, Francisco J. Lozano-García, and Debra Rowe. "Learning outcomes for sustainable development in higher education." *International Journal of Sustainability in Higher Education 9*, no. 3 (2008): 339-351.

Tejedor Papell, Gemma, and Jorge Segalàs Coral "Transdisciplinarity in engineering education. A must for sustainable development in technology education." In *EDULEARN15 Proceedings*, pp. 7083-7090. 2015.

Thürer, Matthias, Ivan Tomašević, Mark Stevenson, Ting Qu, and Don Huisingh. "A systematic review of the literature on integrating sustainability into engineering curricula." *Journal of Cleaner Production 181* (2018): 608-617.

Trad, Sloan, Roger Hadgraft, and Anne Gardner. "Sustainability invisibility: moving beyond technical rationality." Proceedings of the 46th SEFI Annual Conference 2018, pp. 148-157. SEFI-European Society for Engineering Education; Copenhagen, 2018.

UNESCO*, Engineering: Issues, challenges and Opportunities for Development*, UNESCO, Paris (2010)

Warnick, Gregg M. "AC 2011-350: Global Competence: Its Importance for Engi–Neers Working a Global Environment." In *American Society for Engineering Education*. 2011.

Wilson, Denise M., and Mee Joo Kim. "Do Engineering Students View Sustainability Differently from Students in Other Majors?." *International Journal of Engineering Education 34*, no. 6 (2018): 1976-1986.

Wiek, Arnim, Lauren Withycombe, and Charles L. Redman. "Key competencies in sustainability: a reference framework for academic program development." *Sustainability Science 6*, no. 2 (2011): 203-218.

Wulf, William A. "The Urgency of Engineering Education Reform: Incorporating a set of" new fundamentals" into the engineering curriculum and encouraging faculty to practice their craft are among the steps needed to bring engineering education into the 21st century." *BRIDGE-WASHINGTON-* 28 (1998): 4-8. Retrieved January 23rd 2019 from: https://www.nae.edu/Publications/Bridge/EngineeringCrossroads/TheUrgencyofEngineeringEducationReform.aspx.