The role of engineering education for innovation in the 21st century

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Abstract: This conceptual paper first presents a synthesis of the central target and related concepts of five innovation policies from Asia. The paper then identifies how engineering education (EE) can help realise this target. Methods involved online, quantitative, key concept analysis combined with qualitative analysis of units of meaning. Analysis of the polices revealed that the overall target was social and economic prosperity. The prosperity is powered by a capacity for sustainability and inclusivity and by five other sub-categories of capacity as follows: human; relational; research and development; science, technology and innovation and; entrepreneurship and competitive. EE can contribute to social and economic prosperity by helping to build this capacity. Building capacity requires a shift from teaching as telling, to teaching as doing, from transmission of knowledge, to construction of knowledge, from teacher- to learner-centred learning and from didactic teaching to project- and problem-based learning situated in authentic, scientific, social and technological contexts.

Keywords: prosperity; 21st century engineer; sustainability; inclusion; capacity; innovation; progress; economy; social.

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1 Introduction

The challenges facing the world in this first quarter of the 21st century are as complex as they are far reaching. They point to the vulnerability not only of the world's eco-systems and resources but of the humans who inhabit them. In addition to the challenges related to climate change and environmental sustainability, there are global challenges related to poverty, unequal access to services such as healthcare and education, conflict, terrorism and unemployment. The start of the new century presents an opportunity as well as a necessity to address these challenges. That opportunity includes education. However, in order for education to play a role in addressing these challenges it must be relevant and responsive to the global and local contexts in which it operates. Engineering education (EE) is an example of this need for relevance and responsiveness in order for 21st century engineers to "change and transform the world by acting and learning within and from it" [Guerra et al., (2017), p.9].

In spite of the opportunity for EE to play a role in addressing 21st century challenges, in its present form, EE tries "to educate 21st-century engineers with a 20th-century curriculum taught in 19th-century institutions" (Duderstadt, 2010). That curriculum "does not provide the foundation necessary to ensure the engineer's success in the 21st century" [Galloway, (2007), p.56]. Other criticisms of current approaches to EE include: "limited conceptions of learning", "fragmented educational practices" [American Society for Engineering Education, (2009), p.1], a lack of cross-disciplinary perspectives and ineffective integration of information and communication technologies (ICTs) (National Academy of Engineering, 2005). Yet, current and past attempts to improve EE have been surprisingly stable and modest [Crawley et al., (2014), p.241].

2 Purpose and objectives

Given these criticisms of EE, what type of foundation is needed to make it more responsive and relevant to real contexts and global challenges? What demands do real contexts and challenges make on EE? What opportunities do these contexts and challenges offer to EE? Government policies can provide insights into these demands and opportunities. Government policies define a course of action in order to bring about change in order to promote the public good. Particularly relevant in this context of 21st century education are policies related to innovation. Innovation drives economic growth and development and "can help address pressing social and global challenges, including demographic shifts, resource scarcity and the changing climate" [OECD, (2015), p.2]. What does innovation mean for EE in terms of addressing global challenges? To answer that question first requires identifying the central target of innovation policies. What target do the policies aim to realise and how? How can EE support realisation of this target? To answer these questions, this conceptual paper pursued the following objectives:

1. identify the common target of a set of innovation policies
2. identify the central concepts related to the target
3. analyse the relationship between concepts
4. identify how EE can help realise this target.

3 Methods

3.1 Approach

This is a conceptual paper that focused on one context to elucidate a larger phenomenon. Gilson and Goldberg (2015, p.127) described conceptual papers as those that "... do not have data, because their focus is on integration and proposing new relationships among constructs." Instead of a focus on data, the aim is to develop arguments for associations as opposed to testing them empirically [Gilson and Goldberg, (2015), p.127]. Such papers, therefore, seek not to generate theory but to offer insights, and "broaden the scope of our thinking" [Gilson and Goldberg, (2015), p.128] through "offering propositions regarding previously untested relationships" [Gilson and Goldberg, (2015), p.129].

3.2 Context

Asia serves as the context in this paper. Characterised by rapid industrialisation, transformation and economic development, Asian countries represent a relevant context to implement this paper's objectives. From among the Asian countries, only those with a clearly identifiable and articulated innovation policy retrievable online in English were selected. Some countries (e.g., Cambodia and Laos) are only beginning to engage in innovation and therefore could not be included in the analysis. Other countries like Singapore embed innovation in economic policy in general. The countries included in the analysis include India (Government of India, 2013), Thailand (Royal Thai Embassy, 2015), Malaysia (Government of Malaysia, 2013) and South Korea (Government of Korea, n.d.a, n.d.b). Also included is the ASEAN policy on science, technology and innovation (STI) (2016–2025). That policy focuses on the ten-member countries of the ASEAN (2016, 2013).

3.3 Analysis

Identification of the target was supported, in part, by online, digital text analysis (see http://textalyser.net/). This analysis resulted in quantitative word and statement frequency counts. In addition to the unit of analysis of words, methods involved qualitative analysis using the unit of meaning. A unit of meaning is “a statement or a continuous set of statements, which convey one identifiable idea” [Aviv, (2001), p.59]. Analysis of such units across all policies combined with word frequency counts led to the identification of key concepts. The next step involved clustering these key concepts under higher order, more abstract’ categories [Strauss and Corbin, (1990), p.61] using a process similar to what Strauss and Corbin (1998) referred to as axial coding. The categories serve as a ‘container’ for grouping concepts that pertain to each other (Ryan and Bernard, 2003). The next step involved assigning a label to each category. Labels are as astringent as possible in order to accurately capture the varied expressions of the phenomenon across the five different policies. The analysis subsequently relied on what Miles and Huberman (1994) referred to as an inferential and explanatory process of verifying which categories are associated with each other in order to inductively identify the policies’ overall target. To identify how EE can help realise this target, a literature search was conducted. This search was designed to be illustrative as opposed to exhaustive. The search focused on the period of 2000 to 2018 with an emphasis on the last decade.

4 Results of objectives 1 and 2: target and concepts

The central target that emerged from the analysis was as follows: social and economic prosperity powered by a capacity for sustainability and inclusivity and by five other sub-categories of capacity: human; relational; research and development (R&D) STI and; entrepreneurship and competitiveness (E&C). Each of the concepts that make up the target are described and depicted separately in the sections below.

4.1 Prosperity

Prosperity involves both economic and social growth and development. The former encompasses concepts such as economic wealth, productivity, employment, high income, high-value services, knowledge-based economy and society and first world. Economic prosperity is balanced with social prosperity evident in a raised quality of life. Social prosperity is accompanied by a liveable, peaceful, and stable society, societal well-being and opportunity. It is balanced with satisfaction of basic human needs. These needs relate to access to food and water, to security for and protection from economic, environmental and political risk and to access to information and knowledge. Prosperity is underpinned by ethical, humanistic, moral values and awareness.

4.1.1 Inclusive prosperity

The economic and social benefits of prosperity are for all members of society in all regions. All members can also contribute to prosperity. Inclusive prosperity is people-oriented and centred and involves a reduction in social inequality. Gender equality and parity support meaningful, effective and equitable opportunities for women to contribute to and benefit from prosperity. Attention and opportunities are available to ‘those at the bottom of the pyramid’ and to disadvantaged groups. Solutions are accessible and affordable.

4.1.2 Sustainable prosperity

The inclusive social and economic prosperity must be sustainable. This means that growth and development are, therefore, balanced with the imperatives of environmental protection and the need for a green, low-carbon society. Sustainable development relies on green and clean technology and on more environmentally-friendly production and manufacturing.

4.2 Capacity

4.2.1 Human capacity

Human capacity may be characterised by knowledgeable and highly-skilled manpower, talent, a high level of preparedness and unlocked individual limitations. It includes strong mathematical and scientific skills and literacy, scientific temper, talent, public understanding of science, technology competency and STI potential. In addition, it includes artistic sensibilities, ingenuity, curiosity, can-do and entrepreneurial spirit, creativity, passion and intelligence and an ability to create and apply knowledge.

4.2.2 Relational capacity

Relational capacity values the relations between humans, organisations, or nations. Relational capacity, therefore, is the capacity to create, rely on and engage in relationships. This capacity depends on cooperation, collaboration, convergence, coordination, harmonisation, inter-dependence, interconnectedness, international relationships, strategic partnerships, business relationships and global alliances, people-to-people connectivity and joint undertakings. This capacity involves sharing of research facilities and manpower, know-how, information, ideas and suggestions. It requires effective communication, proactive dialogue and dialogue partners. Networks, innovation and creative hubs, industrial clusters and linkages serve as mechanisms to foster relationships. The relationships include partnerships between industry, academia, private and public sectors, scientific and social-economic sectors and government research institutions. Relational capacity includes mobility and exchange of talent, experts, and of scientists and researchers. It extends to the regional, local and global community, markets, businesses and brands.

4.2.3 R&D capacity

R&D capacity relates to a nation's ability and resources to generate, transmit and diffuse knowledge to the public sector, industry, communities and society. R&D involves integrating knowledge across disciplines, converting knowledge into wealth. Forms of research include technology, scientific and social as well as basic, applied, interdisciplinary, integrated and market-driven research. Research may be conducted transnationally between universities, in organisations, research hubs and clusters, in industry-specific research institutes, in publicly-funded R&D centres or large R&D facilities. It may be fostered through joint research, cultivation of investment and private sector investment. It may also include crowd-funding for creative ideas, creative hubs and platforms.

4.2.4 STI capacity

STI capacity draws on accessible and affordable ICTs, ICT infrastructure, science infrastructure, advanced technology, robotics and automation, technology development and transfer and rigorous integration of science. It offers science- and technology-based solutions. STI capacity involves deep enculturation with STI as a foundation and mainstreamed into citizens' lives. STI can be seeded and sustained by leveraging ICT. It can include a fusion of technology, culture, strength in science, scientific literacy, technological competence and self-reliance and creativity and passion in STI. STI knowledge can be transmitted and diffused to the public and private sectors. STI capabilities for industry can be strengthened.

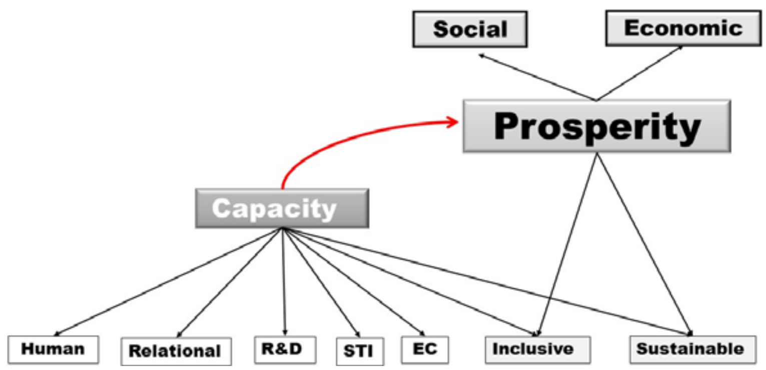
4.2.5 Entrepreneurship and competitive (E&C) capacity

E&C capacity results from development, promotion, support and reduced barriers for startups and small and medium enterprises (SMEs) and for those wanting to start a business. This means assisting SMEs and startups to go global, facilitating access of SMEs and startups to the free market and to global markets. Student startup clubs, investment in young entrepreneurs, and expanding entrepreneurship education provide opportunities for young people and women to enhance their entrepreneurship. Other opportunities include entrepreneurship seminars, one-stop services for aspiring entrepreneurs, science-led and STI entrepreneurship and industry-tailored assistance for entrepreneurs. In addition to the promotion of and support for entrepreneurship, of SMEs and startups, advancing commercialisation is part of E&C capacity. Hubs can serve as places to turn ideas, technology and STI initiatives into commercial success and there may be incentives for commercialisation of innovations for the creation of local jobs and new industries. E&C capacity also relates to the importance of competitive advantage. This advantage involves building a competitive nation and economy, raising and encouraging competitiveness and gaining global competitiveness, for example, in high-technology areas.

5 Results of objective 3: analyse the relationship between concepts

Analysis of the relationship between the concepts shows that inclusivity and sustainability are properties of the target of prosperity. Likewise, the prosperity is not merely inclusive and sustainable economic prosperity: it is also inclusive and sustainable social and economic prosperity. Five forms of capacity are drivers of inclusive and sustainable social and economic prosperity. Although they were each presented separately in the previous section, in fact, they work together and not independently of each other. This means, for example, that the human capacity needs to be a relational human capacity in order to contribute to prosperity. Capacity is more than capital. Human capital refers to "the knowledge, skills, competence and other attributes embodied in individuals that are relevant to economic activity" [OECD, (1998), p.90]. Unlike capital, a concept that is at the service of the economy, capacity involves strengths, capabilities and attributes that can be developed and harnessed to achieve certain goals. These goals can be social as much as they are economic. Instead of aiming for economic prosperity driven by capital, the policies aimed for prosperity that is also social and that is driven by capacity, including that for sustainability and inclusivity. In this context, capacity is not at the service of inputs to production. Capacity is aimed at transformation, growth and development that lead to social and economic prosperity. Figure 1 illustrates the relationships between the concepts.

Figure 1 Relationships between the concepts (see online version for colours)



6 Results of objective 4: how EE can help realise this target

The central target of the five policies is the achievement of social and economic prosperity. The prosperity is powered by a capacity for inclusiveness and sustainability and by five other forms of capacity: human, relational, R&D, STI and, E&C capacity. EE can help build and contribute to these seven forms of capacity both within EE and in society. The following sections provide a review of the literature of relevant to achieving this target.

6.1 Capacity for inclusion

Inclusion can be understood as "incorporation of different perspectives, values, and ways of thinking and being in engineering" (Zoltowski et al., 2017). To promote inclusion, EE programs can formally adopt the UN's (2016) pledge that no one will be left behind. They can invite, allow and support participation from individuals regardless of gender, disability, faith, socio-economic status, political or sexual orientation, race, ethnicity or culture (Delaine et al., 2016). Inclusion may be promoted by affirmative action efforts (Delaine et al., 2016) and by facilitating and encouraging collaboration with minority and underrepresented groups (National Science Foundation, 2008). Overall, EE institutions themselves can become more inclusive through adherence to the UN's (2016) Sustainable Development Goals' (SDGs) recommendations such as transforming power relations and incentives in institutions. Other approaches to building inclusion involve a 'multi-pronged approach' that focuses on the 'visible and invisible' aspects of diversity, and that provides role models, peer mentoring and efforts to make engineering 'more appealing to a more diverse population' (Forin et al., 2017). Mentors can also support and help develop a sense of belonging among marginalised members while cultural sensitisation and development of cultural competence and socio-emotional sensitivity can help with retention (Delaine et al., 2016).

In general, the literature on EE is replete with calls for increased inclusion of females. However, initiatives to include individuals from underrepresented groups and diverse backgrounds in EE programs need to be accompanied by efforts to retain them (Wall, 2010). These efforts can include normalising the female experience to make it more ‘hospitable’ and by providing opportunities for hands-on experiences for those not accustomed to ‘tinkering’ and for those who may not be engaged by theory (Wall, 2010). Inclusion also involves diverse faculty in programs with proactive measures to attract, for example, female faculty members (Wall, 2010) and to provide them with opportunities to reach tenure and to occupy positions in upper-level administration (Delaine et al., 2016). Women in the Arabian Peninsula and Saudi Arabia as well as ‘locally marginalised groups’ can benefit from increased access to higher education through distance learning and an open university (Mazawi, 2015).

Disadvantaged groups and institutions that may not have access to facilities, textbooks or other resources can make use of online resources, learning objects and facilities (Banday et al., 2014). An example of efforts to include individuals from disadvantaged groups involves an initiative by a Chilean university to recruit students from low-income backgrounds through reliance on alternative admission criteria that considers not simply standardised test results but personal skills (see Hilliger et al., 2016). Other efforts to retain and recruit diverse students involve monitoring the impact of inclusion and diversity efforts in engineering faculties and institutes through surveys of students’ experiences of inclusiveness (Lee et al., 2014).

To contribute to building inclusiveness, engineers in formation can plan for and execute designs that accommodate diversity and that promote inclusivity and accessibility. These designs might better accommodate the needs of more vulnerable populations such as seniors or the disabled. Engineers in formation might work on complex problems experienced by marginalised groups such as refugees in large camps where access to water, information and food call for unique solutions. To help build inclusiveness, the types of problems that engineering students are given or adopt should reflect social and not only technical challenges. They should reflect problems faced not only by those in first-world countries but by populations rendered vulnerable as a result of environmental crises, social conflict, political or economic instability.

6.2 Capacity for sustainability

Forms of learning that can promote sustainability include experiential and community-based learning (Olds et al., 2012) and pedagogies of engagement in which students are active and engaged in the learning process (Smith et al., 2005). EE students may benefit from involvement with engineers without borders and problem-based learning projects in which they work in teams to identify community needs and implement solutions (Wittig, 2013). EE curriculum can provide opportunities for greater global awareness projects and activities that involve social engagement and social justice such as community-development work (Litchfield and Javernick-Will, 2015). Wall’s (2010) report on challenges facing engineering noted the need to de-emphasise formulaic learning and emphasise project- and problem-based approaches. These approaches might focus on real ethical issues such as poverty reduction to prepare engineers for real-life future challenges (Wall, 2010). Sustainability can be promoted through required courses, intertwining the concept in a course (De Werk and Kamp, 2008), specialisations in EE for sustainable development (EESD), flagship courses, lunch-time seminars, guest lecturers or full degrees (Wall, 2010). To promote sustainability, EE needs to establish "acting-in context as the norm at the university level (e.g., integrating students in professional work on a more regular basis) as well as ensuring learning-in-context at the professional level" [Kastenhofer et al., (2010), p.50].

In general, sustainability requires that students become more socially and environmentally aware and responsible, that they have knowledge of current, global issues and be able to engage in systems' thinking (Lathem et al., 2011). It demands that they "include sustainable development in their way of thinking" [De Werk and Kamp, (2008) p.929]. In EESD, the engineer is "a social, political, and ethical persona" who is provided "opportunities to learn and reflect upon one's actions, the beliefs underpinning them, and their outcomes, in the context of professional agency" [Kastenhofer et al., (2010), p.47]. Students can learn to engage in "designing through the lens of scarcity [which] begins first with the assumption that material and human infrastructure are limited...." [Niemeier et al., (2014), p.1287]. This approach calls for "engineering designs that reflect the unique needs and constraints of low resource settings" [Niemeier et al., (2014), p.1228].

To understand the foundations of sustainability, EE students can be exposed to topics such as "environmental impacts, globalization, population growth and its general impact on resource use...the social-cultural-political-ethical-and moral impacts of development, global crises and problems that confront mankind and the wider environment, and the irrelevant impacts on society and future generations" [Al-Rawahy, (2013), p.398]. Likewise, students can be presented "with projects that ask them to consider how their designs contribute to the human, ethical and natural domains" [Lau, (2010), p.258].

EE also has a responsibility to support the UN's (2016, p.22) SDGs by ensuring that engineering designs result in 'infrastructure resilient to disasters'. To support achievement of the SDGs, EE needs to promote technology use in ways that are sustainable. The UN (2016, p.48) recommended development of "technology roadmaps for most SDGs, in cooperation with engineering academies." Sustainable designs may be promoted through what Staniškis and Katiliūtė (2016) referred to as the need for 'contextual awareness' whereby engineers appreciate and evaluate the consequences of their actions and designs within social, legal and cultural contexts as well as scientific, economic and technical ones. Such awareness means having the "ability to anticipate the consequences of decisions and to act appropriately [with] a proactive rather than reactive approach" [Staniškis and Katiliūtė, (2016), p.13]. Along with the awareness, there should be an appreciation for 'the human dimensions of technology', as well as 'knowledge of global issues, and sensitivity to cultural diversity' (Wulf and Fisher, 2002).

6.3 Human capacity

Engineers of the 21st century need to be more than mechanics, labourers and technicians (Capobianco et al., 2011). What is ideally needed to promote social and economic prosperity is a "holistic breed of engineer – one who can work across borders, cultural boundaries, and social contexts and who can work effectively with non-engineers" [Galloway, (2007), p.46]. Various approaches have already been proposed to foster the development of this 'new breed'. Many of these approaches are based on the same argument that students require a broader and more diversified course load. The National Academy of Engineering (NAE) (2005) proposed that EE programs should include the humanities along with interdisciplinary subjects, economics, political science and language. Grasso and Helble (2007) described requirements for an accredited engineering degree that included entrepreneurship and the liberal arts. The program required a final project in which students ‘pursue their personal artistic, humanistic, philanthropic, and technical interests’ so that they can be ‘well-rounded and balanced’.

Alternative perspectives on the human capacity of the engineer of the 21st century have been put forth by the American Society of Civil Engineers (ASCE) (2009). The ASCE proposed that, in the future, tasks that, in 2017, might be completed by an engineer will, in 2025, be completed using computers and with paraprofessionals such as technicians. Professional engineers will, instead, occupy a ‘broader, higher, more professional role’ [ASCE, (2009), p.17]. Recommendations of a report regarding preparing engineers for 2020 emphasised that “engineering schools must teach engineering students how to learn and must play a continuing role along with professional organizations in facilitating lifelong learning…” [National Academy of Engineering, (2005), p.55]. Advances in technology including distance and asynchronous learning could enable and support lifelong learning (National Academy of Engineering, 2005).

Others argue that it is not the structure of programs that necessarily needs to change but the approach to pedagogy. For example, Mills and Treagust (2003, p.4) proposed a ‘radical approach by shifting the fundamental basis’ to learning that is problem and project-based (PPL). Such an approach recognises that, while knowledge and certain skills may be taught in a lecture or traditional courses, other attributes may be better developed in constructivist and learner-centred contexts. In these contexts where students are actively constructing knowledge and identifying solutions to real-world problems, attributes such as curiosity, creativity and passion are called into play. Furthermore, PPL aligns very closely with the aims and activities of professional practice and is a relevant and authentic context in which to develop human capacity in EE. Mills and Treagust (2003, p.12) described an Australian program in which 50% of students’ time is spent on project-based learning (PBL) which involves “developing skills in team-work, communication, computing, problem-solving and others, as well as introducing students to engineering issues such as ethics, environmental and social factors.”

Open-ended design activities and projects can provide opportunities for creativity. Cropley (2015a) proposed reliance on open-ended, flexible design projects along with challenging tasks, ill-structured problem solving, risk taking and modelling of creativity by instructors. Cropley (2015b) drew on Sternberg’s (2007) habit of creativity to propose that EE embed and integrate opportunities for creativity into the curriculum and that students be encouraged to engage in creative tasks and rewarded for creative achievement. Daly et al. (2014) recommended that instructors clearly communicate goals for creativity within their planning and assessment through, for example, using rubrics with specific indicators of creativity. They also proposed that EE instructors focus more on ‘originality, elaboration, and metaphorical thinking’, that they develop activities that develop specific creative skills and that they encourage reflection and tolerance of ambiguity among students. Engineering students should also develop systems’ thinking and design through context-driven inquiry and “higher order creative and critical thinking that begins with experience and observation” [Godfrey et al., (2014), pp.112–113].

Creativity can also be integrated into project and problem-based learning (Zhou, 2012). Creative thinking can be enhanced through reliance on ICTs (Sale, 2014).

6.4 *Relational capacity*

Teams are a natural tool for building relational capacity. Students should be introduced to "team-based design projects ... early in the undergraduate experience" [National Academy of Engineering, (2005), p.40]. While working in teams, they can learn to communicate effectively, develop interpersonal skills, resolve conflict, share decision making and show accountability to each other (Mills and Treagust, 2003). Teams can be enabled for greater creativity when diversity in team composition is privileged [Chubin et al., (2005), pp.73–74]. Teams should develop positive interdependence and accountability as well as positive peer relationships [Smith et al., (2005), p.32]. Carefully-balanced teams represent a means to ensure adequate levels of skills, knowledge and pertinent attributes required for engineers to deal with complex, real-life tasks, projects, problems and designs. In this regard, relational capacity can build on human capacity by balancing teams with a diverse range of skills, knowledge and attributes that result in the sum being greater than the total. Teams can include professional and non-professional personnel (Mills and Treagust, 2003).

Building relational capacity also involves developing global competence or "the ability to work knowledgeably and live comfortably in a transnational engineering environment and global society" [Lohmann et al., (2006), p.119]. This competence requires "coursework in international studies, language proficiency and an immersive international experience" [Lohmann et al., (2006) p.123]. Downey et al. (2006, p.1) argued that global competency (GC) for EE involves the capacity to "work effectively with people who define problems differently." Downey et al. (2006) described approaches to achieving GC such as international educational and work experiences, elective courses such as 'engineering cultures' and integrating the pursuit of GC into EE curriculum. Collaboration, partnerships and formal alliances between engineering educators and academic humanists can help "impute humanistic concerns into the problem-solving strategies of engineers" [Sjursen, (2007), p.135].

Developing this GC in EE has been made easier through the use of online technologies that allow for anytime, any-place, organisationally, culturally and geographically diverse communication and collaboration. Students in Berthoud and Gliddons' (2017) study relied on wikis for communication, collaboration and engagement in projects. The authors noted that wiki metrics offer a potential means to measure and monitor the quality of group collaboration. Virtual teamwork using networked computers 'challenges the disadvantage imposed by physical distance' allowing team members to collaborate even when they are not physically co-located [Line, (1997), p.1]. The key to success of such teams is communication and social and professional relations as well as the balance between technical versus social issues (Line, 1997). Virtual reality (see Sheppard et al., 2004; Shuman et al., 2005) can support international and multicultural virtual design teams. Collaborative learning through experiments can take place in online laboratories (Zhai et al., 2012). In general, technologies for collaboration can support 'sharing of ideas, materials, and other resources.' [National Academy of Engineering, (2005), p.34]. Intercultural and socio-cultural competencies can also be developed through gaming simulations (Ekaterina et al., 2015). Peer learning of open-ended problems can be supported using mobile devices and virtual learning environments (Siddique et al., 2013). In addition, sharing between universities and institutions is made easier through reliance on online, virtual laboratories and sharing of online courseware (Banday et al., 2014).

6.5 R&D capacity

Learning should not depend on approaches that involve merely transmission of knowledge from instructor to students in a teacher-centred classroom. Instead, the capacity for R&D demands that students engage in higher levels of thinking that engage them as inquirers and researchers. In inquiry-based learning, students behave as would a scientist: “formulate good questions, identify and collect appropriate evidence, present results systematically, analyze and interpret results, formulate conclusions, and evaluate the worth and importance of those conclusions” (Lee, 2004). Engagement in inquiry can be supported by reliance on inductive learning. Inductive learning relies on constructivist, learner-centred methods such as ‘inquiry learning, problem-based learning, [and] project-based learning...’ and on ‘the need to know’ [Prince and Felder, (2006), p.123].

EE students can engage in research as part of or in place of certain coursework. One example is a team of engineering students in Thailand led by a doctoral student. The team gathered information about the needs of a particular community and subsequently implemented engineering designs related to those needs [see Suvannatsiri et al., (2015), p.1]. The undergraduate civil engineering students “designed, constructed and tested a model of an existing early warning system ... in a context of a landslide.” Students gathered data onsite about the system and about the villagers’ knowledge of the system, created a model of it, simulated a landslide and then taught villagers how “to estimate the time needed for evacuation of the community in the event of a landslide.”

EE students can take advantage of opportunities to conduct inquiry that would normally not be possible without the support of computers. Conducting inquiry in virtual laboratory settings can offer access to phenomena that would normally be unobservable and where safety would be an issue in a real versus simulated context (de Jong et al., 2013). Using computers, learners can access data and conduct ‘rapid data analysis and presentation’ [Feisel and Rosa, (2005), p.121]. They can access open, online computational environments such as that featured by Kaggle (https://www.kaggle.com/competitions) and that provide access to thousands of authentic data sets related to real-world problems and real inquiry.

6.6 STI capacity

Technology puts pressure on EE to be at least up to date with, if not the main driver of, technological growth. Future engineers will need to “learn much new technical information and techniques and be conversant with and embrace a whole realm of new technologies” [National Academy of Engineering, (2005), p.8]. At the same time, the emergence of new technologies including ICTs means that engineering can carry out its “central purpose ... increasingly from a computer terminal and not from the workshop floor or a field truck” [Fiesal and Rosa, (2005), p.128].

Independent of technology, building capacity in STI involves helping future engineers learn how to innovate in order to devise novel solutions to new and old, complex, real-life problems. Innovation pedagogy can be integrated with the CDIO approach to emphasise 'creation of innovations', and a capability to 'participate in diverse innovation processes' and 'innovation competences' [Penttila and Knotio, (2014), p.435]. Innovation pedagogy includes elements such as an 'integrated and flexible curriculum', a constructivist approach, social, active and experiential learning and assessment of innovation competences (Penttila and Knotio, 2014). In general, Radcliffe (2005, p.199) argued with regard to innovation in EE that an ability to innovate "has major implications for not only what is taught but also on the educational culture in which it is learned, especially in terms of nurturing the emotional competencies." Creativity can be considered an innovative trait (Radcliffe, 2005).

Building STI capacity demands more than merely "a transmission approach focusing on mastering the underpinning science and mathematics basics" [Royal Academy of Engineering, (2014), p.38]. STI capacity calls for scientific literacy and inquiry and a scientific mind. In EE, scientific inquiry relies on an inductive approach to learning (Prince and Felder, 2006) whereby students solve increasingly complex problems and answer more complex questions. Engagement in scientific inquiry involves using evidence to explain and justify assertions (Hofstein and Lunetta, 2004). A scientific mind includes but is not limited to habits such as objectivity, rationality, and scepticism (Çalik and Coll, 2012; Royal Academy of Engineering, 2014). Roth and Lee (2002, p.53) argued regarding scientific literacy for the need for "conversations to emerge in which different forms of knowledge are negotiated and geared to particular problems as these arise in the daily life of a community."

6.7 E&C capacity

Building E&C capacity involves fostering an entrepreneurial mindset. Approaches to developing an entrepreneurial mindset include problem-based learning (Warren et al., 2006), entrepreneurship case studies (Weaver and Rayess, 2008), entrepreneurship programs (Shartrand et al., 2016), and project-based entrepreneurial leadership (Okudan and Rzasa, 2006). Pittaway and Edwards (2012, p.10) classified types of courses in the categories of about, for, through, and embedded forms of entrepreneurship education with the 'about' form dominating undergraduate education using a traditional, didactic focus on knowledge accumulation. An example of an experiential entrepreneurship program in EE is one hosted in an American EE program that offers differing 'layers of opportunity and engagement' depending on students' interests (Conger et al., 2010). The experiential program is one of three designed to increase "engineering student wisdom as creative and innovative change agents." Odora (2015, p.281) found that entrepreneurship can be best taught using "a methods-based approach that supports iteration and creativity" and using modules in which "engineering problem solving takes place in the context of a business opportunity." Pittaway and Edwards (2012, p.6) described an approach to entrepreneurship that engages learners in "real projects or activities in order to get close to the lived experience of entrepreneurs." An alternative approach to developing entrepreneurial skills involves contests, 'friendly competitions', students' clubs, startup cafés and offering awards and prizes (Sperrer et al., 2016).

In general, Besterfield-Sacre et al., (2016, p.22) argued that "teaching entrepreneurship incorporates more than just knowledge and skills and that affecting mindsets and attitudes is equally important…" An entrepreneurial mindset exists in conjunction with creativity (Barba-Sánchez and Atienza-Sahuquillo, 2017). The entrepreneurship mindset involves "the desire to achieve, the passion to create, the yearning for freedom, the drive for independence, and the embodiment of entrepreneurial visions and dreams through tireless hard work, calculated risk taking, continuous innovation, and undying perseverance" (Ma and Tan, 2006). Entrepreneurial skills needed by engineers include technical, management, problem-solving and leadership skills (Mohanty and Dash, 2016).

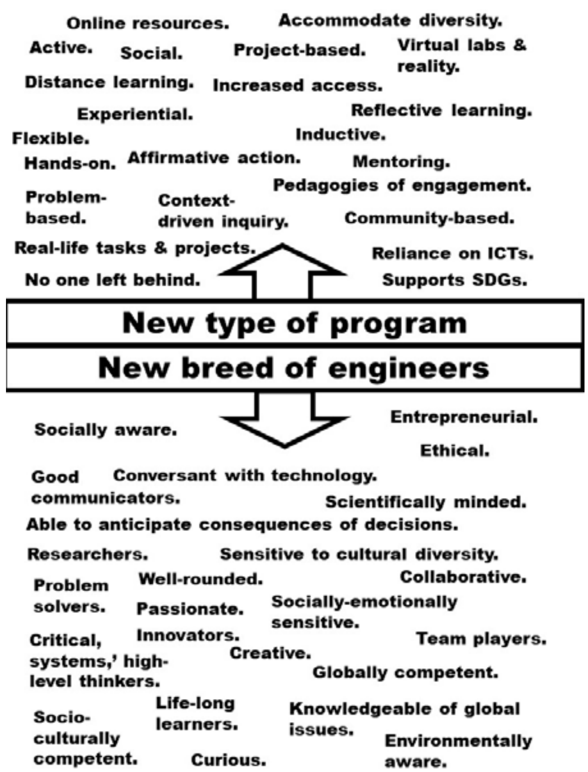
For EE, a competitive capacity can be fostered through initiatives such as that described by Kanyarusoke (2017) whereby students are given 'real engineering business situations', then work in teams 'to competitively solve progressively complex problems'. A similar initiative was undertaken using problem and PBL with groups acting as startups who submitted syllabus-related projects in which they competed for investment with others in the class who played the role of potential investors (Giordani et al., 2017). The European Project Semester offers a cross-cultural EE experience across 12 countries and involves project-based teamwork between international students designed to develop skills related to cooperation, communication and competition (Andersen, 2007). Carroll (2013) described competition-based learning (CBL) as PBL, with teams and open-ended assignments using scaled-down version of authentic professional engineering problems and competing for the 'best overall project'. CBL is designed to promote students' motivation, engagement, self-learning and active learning. Case competitions in which students are required to solve authentic business and engineering problems are another approach to building capacity for competitiveness. Lynch et al. (2016) described one project whereby students in an industrial Engineering program participated in a case competition sponsored by a 'US retailer' and that incorporated a real-world problem related to a recycling program. The competition offered a monetary prize by the retailer and counted for a percentage of the course grade.

7 Discussion and conclusions

This conceptual paper presented the central target and relationships between concepts of five innovation policies. It subsequently identified ways that EE can help realise social and economic, inclusive and sustainable prosperity. EE can contribute to social and economic prosperity by helping to build capacity both within itself and in society. To do this, requires attention not only to attributes of EE programs, but also to the attributes of engineers themselves. Figure 2 summarises these attributes both in terms of the program and future attributes of engineers themselves. These are representative (though not necessarily exhaustive) of the attributes relevant to realising the target.

The identification of personal and program attributes for 21st century EE made evident that EE and engineers have not only a technical role to play in the 21st century but also a social role. The need to develop a capacity for inclusive and sustainable designs highlights the social responsibility of engineers and EE programs. It shifts attention away from what Pool (2003) described as a tendency for engineers to see their work in positivist, objective, scientific and technical terms. It points to the need for engineering to play a role in reducing social injustices (Catalano, 2006) and portrays EE as more than the application of science and mathematics. Ultimately, assigning a social justice role or even merely a social role to EE and engineers will require adopting new narratives about the profession. In practical terms, it means adding courses or components to courses to target the development of attributes such as sensitivity to social contexts in order to solve complex problems in those contexts [e.g., Gosink et al., (2004), p.48]. However, Galloway (2007, p.49) argued that simply adding more courses to the curriculum ‘is not a viable solution’ to the need to build particular attributes in students. Galloway posited that what is required to meet the challenges of the 21st century is to go beyond the four years of undergraduate study to acquire a graduate level of education. Likewise, the National Academy of Engineering (2005) proposed that a bachelor’s degree be considered as pre-engineering with a master’s degree as the professional degree. There could be ‘post-baccalaureate professional schools, similar to medicine and law’ [Duderstadt, (2010), p.13]. The baccalaureate would serve “as preparation for further study in an engineering professional school.” It would consist of a “pre-engineering foundation in science and mathematics’ as well as well as courses in the humanities, liberal arts or social sciences” (Duderstadt, 2010).

Figure 2 Summary of personal and program attributes for 21st century EE



Regardless of how programs are added, or courses designed, building capacity is unlikely to be achieved with approaches to learning that are chalk-and-talk, teacher and content-centred. Approaches with learners in the role of passive recipients of expert knowledge are also unlikely to be effective in building capacity for social and economic prosperity. Building capacity for social and economic prosperity requires more than merely additions to its length, scope and breath. Adding courses, components, modules and even years to

EE can potentially overburden programs and curricula. Furthermore, the additions may not necessarily equip students with the complex attributes and soft skills required to effectively contribute to prosperity that is at the same time sustainable, inclusive, social and economic.

EE curriculum "is expanding beyond the point where programme revision can absorb all of the new demands" [Sjursen, (2007), p.141]. Instead, what is required is, not additions to, but a shift in EE. This shift moves EE from teacher- and content-centred approaches to embrace a constructivist approach that puts the learner at the centre of an active and engaged learning experience. For 21st century EE, this involves engagement in collaborative, authentic, ill-structured problem solving. The shift includes a move away from individual learning to team-based and PBL. It also means a shift away from teaching as telling and transmission of knowledge to focus instead on developing higher levels of thinking including analytical, critical and creative. In this approach, theory and practice are integrated through knowing and doing and situated in activity that matches as closely as possible the problems in actual contexts of practice. Learning is underpinned by a spirit of scientific inquiry combined with curiosity and passion and a respect for social justice. In this rich context, the engineer in formation (EF) learns to identify the knowledge and skills needed for present and future contexts of collaborative problem solving. The EF learns to think, plan, design and, most importantly, evaluate the consequences of the designs to ensure and promote sustainability. Most importantly, the EF learns to problem solve and learns to learn in order to continuously contribute to sustainable and inclusive, social and economic prosperity.

This perspective on EE is congruent with other perspectives in the literature. Attempts to build these forms of capacity are evident in the CDIO approach and the Aalborg PBL model. Both CDIO and the Aalborg PBL model are underpinned by a learner and problem-centred constructivist approach to learning. CDIO offers a vision of EE based on teamwork and active, experiential learning (see http://www.cdio.org/cdio-vision). The Aalborg PBL model, as a way of 'organising learning', relies on problem/PBL as an alternative to subject-oriented EE (see Aalborg University, 2010). The model relies on a systematic framework of nine principles and promotes active peer learning with teacher as 'initiator and facilitator' (Aalborg University, 2010). Problems are meant to be situated in a context and exemplary in terms of referring to 'a particular practical, scientific and/or technical domain' (Aalborg University, 2010). Projects are undertaken in teams and provide a means to link theory with practice.

Perhaps more than any other profession or field, engineering is positioned to play a role in building a world that is not merely economically prosperous but socially prosperous. To do so will require new approaches to learning. It will require not only educational reform but a fundamental rethinking of what it means to be an engineer. That rethinking must be grounded in new visions for the future. These visions can be guided by policies such as those outlined in this paper; policies that put humans at the centre of development and that see innovation as a means to build better lives for all. As Galloway (2007, p.47) argued, "our educators must instill within their students the belief that engineers are engaged in creative, stimulating, challenging, and satisfying work that significantly improves the lives of people the world over." The responsibility of improving the lives of others is a serious one. It is a reminder that engineers are ultimately positioned to be 21st century leaders. The question that remains is whether EE programs can prepare them for that role.

8 Limitations and future directions

This paper was limited to a focus on Asia and, within that context, explored the policies of four countries in addition to the ASEAN policy. Analysis of a set of policies from other parts of the world, particularly those of more developed countries, may have resulted in the identification of different targets and concepts and, subsequently, other ways for EE to achieve social and economic prosperity that is inclusive and sustainable. Future inquiry might focus on measuring capacity building in particular EE programs by asking questions such as: How well does the program develop relational capacity? How can development of human capacity be measured as a product of relational capacity? Which of these capacities is the most or least required for prosperity?

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