A Model of Engineering Education for Innovation

Abstract— **The purpose of this paper is to present implications of innovation for Engineering Education (EE) and research. The specific objectives are as follows: Analyze innovation policies from India, Malaysia, Thailand, Korea and the Association of South-East Nations (ASEAN): Identify common themes between policies; determine implications for EE for Innovation (EEFI); create a model of EEFI; determine implications for EEFI research. Analysis of the policies led to the identification of seven themes: prosperity, humanity, inclusivity, capacity, sustainability, inquiry, and community. These themes guided the creation of a model of EEFI. The model consists of four principal bases: learner-based; STEM + AE-based, problem-based and; project-based. Learner-based focuses on what engineers are in terms of their personal and professional competencies. STEM + AE are a reminder that engineers must be more than technicians, well-versed in STEM. Their education needs to include the arts and entrepreneurship. The problem base refers to EEFI activity being driven by complex, authentic, ill-structured challenges, problems and issues that have a social as well as a technical character. The project-base involves collaborative efforts to find answers to questions and create solutions to problems and challenges. Implications for research highlight a range of approaches to researching EEFI from quantitative surveys of perceptions of participants to complex research designs whereby engineers in training are collaboratively solving real problems in communities.**

Keywords— Engineering education; innovation; research; STEM; model, Asia, higher education, pedagogy,

I. Introduction

Rapid changes brought about by the prevalence of networked devices and information and communication technologies (ICTs) have forced governments and industry to innovate in order to remain competitive in what has become a global market. Innovation has also become necessary to face the growing economic and social challenges affecting the globe [1]. Various terms, strategies and initiatives have emerged that reflect this impetus for innovation. One of these is *Industry 4.0.* The term refers to a fourth industrial revolution driven by phenomena such as the *Internet of Things* and by automation and digitization processes [2]. Countries around the world have adopted strategies and policies to keep pace and conform with *Industry 4.0*. Under President Obama's leadership in the USA, *The Nation of Makers* strategy encouraged youth and adults to create, invent and innovate [3]. The UK's *Design in Innovation Strategy* (2015-2019) involves using design to innovate and generate more value in order to accelerate economic growth [4]. Germany's innovation strategy dubbed *The High-Tech Strategy*, focuses on both technological and social innovation [5].

The innovation strategy of the Organization for Economic Cooperation and Development (OECD) emphasizes the need to empower people and enterprises to innovate, create and apply knowledge to face challenges. The OECD argues that innovation is powered by human capital through education and the generation of ideas and knowledge, development of wide-ranging skills and of a capacity to learn and relearn. The emphasis in education according to the OECD, must be on building capacity for lifelong learning and for critical and creative thinking. School and universities have a critical role to play as "bridges" of innovation in terms of forming innovation clusters and engaging in multidisciplinary, collaborative research that interacts and networks with industry and the private sector. Vocational education needs to be connected to the world of work. Finally, the OECD recognizes that innovation thrives on diversity which includes women and other underrepresented groups. It also requires "mobile talent" fostered through international and cross-border networks of knowledge in higher-education [1].

The capacity for development and innovation in countries depends on human capital such as that provided by engineers [6]. Engineering education (EE) has a pivotal role to play in fostering, managing and sustaining innovation. This role requires an "integrative education model" that can produce a "new kind of innovation engineer" capable of leading and driving change not only at the technical level but socially and culturally [7]. An integrative model of EE will need to move beyond science, technology, engineering and mathematics (STEM) as a foundational component. New forms of learning (e.g., lifelong, active, collaborative, and problem-based) have been advocated in the research literature. Likewise, there is increasing reference to engaging learners in higher levels of thinking (e.g., creative) and new metaphors for learners (e.g., learners as problem-solvers). New models will require a dismissal of the "business-as-usual" attitude that has dominated EE [8] and moving beyond the "surprisingly stable," and "modest reforms" that have thus far dominated the pedagogy of EE [9].

A. *Purpose and Objectives*

The broad purpose of this paper is to present implications of innovation for EE. The specific objectives of this paper are as follows:

1. Analyze five innovation policies from Asia;
2. Identify common themes;
3. Determine implications of these themes for EE for

Innovation (EEFI);
4. Create a model of EEFI;
5. Determine implications for research related to EEFI.

The case adopted for the consideration of the implications is select countries in Asia. Characterized by rapid industrialization, transformation and economic development, Asian countries represent a relevant case in which to explore the implications of innovation for EE. Identification of the implications will be relevant to the design of EEFI programs as well as for professional development and training in industry within Asia and around the world. The implications will also have relevance for industrial-education programs that train teachers for technical and vocational engineering.

B. Selection of Countries and Innovation Policies

The selection of policies is intended to be illustrative as opposed to exhaustive. From among the Asian countries, only those with a clearly identifiable and articulated innovation policy retrievable online in English were selected. Some countries are only beginning to engage in innovation and therefore could not be included in the analysis (e.g., Cambodia and Laos). Other countries like Singapore embed innovation in economic policy in general. The countries included in the analysis include India, Thailand, Malaysia and South Korea. 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.

II. INNOVATION POLICIES

This section of the paper corresponds to objective 1: Identify innovation policies in select Asian countries. The section provides an overview of the policies of Thailand, Malaysia, India, South Korea, and the ASEAN.

A. Thailand [10,11]

Thailand 4.0 is an economic and innovation development model that relies on advanced technologies to move the country from a middle to high-income, first-world nation. The model relies on four objectives: economic prosperity; social security and well-being; human values and; environmental sustainability. Economic prosperity involves moving towards a knowledge-based economy driven by research and development (R&D), STI and creative thinking. Social security involves building an inclusive society, realization of the full potential of all members, a reduction in social disparity and transformation of the social welfare system resulting in equitable access to prosperity. The objective of human values focuses on transforming Thais into more competent human beings, as first-world citizens though social opportunities and financial supports. Transformation will require educational reform that includes the offering of skills-development programs. It will also include replacing routine jobs with robotics and automation, unlocking individual limitations, promoting social opportunities and a shift from traditional to smart farming, enterprises, and high-value services. Thailand 4.0 includes encouraging universities to develop technology and innovation. It promotes international cooperation and alliance between universities that will propel research. Environmental protection and sustainability relate to a balance in economic and social development. This strategy promotes, not only livable cities, environmentally-friendly development and an ability to adjust to climate change, but also a reduction in terrorism risk.

B. Malaysia [12]

Malaysia's National Science, Technology and Innovation Policy aims for a high-income, scientifically advanced, peaceful, healthy, prosperous, resilient and green nation achieved through inclusive and sustainable socio-economic transformation and growth. The policy highlights a foundation of "strong ethical and humanistic values." Strategic initiatives include integration of social sciences and humanities research with sciences and increased spending on research, development and commercialisation (R, D&C) of innovative products. The emphasis on nurturing, retaining and using STI talent is in response to a past outflow of talent to other countries such as Singapore. This strategy involves increasing the ratio of researchers to the workforce along with the development of higher-order cognitive, analytical, creative and innovative skills. The policy also encourages equitable female participation. Initiatives include a focus on the private/public R&D expenditure ratio; promoting private sector R, D&C, networking and knowledge transfer to industry, social and grassroots-driven innovation, collaboration and partnerships and promotion of an innovative and risk-taking culture. It aims to create public awareness about STI along with awareness of ethics and humanities in society. The final strategy highlights the role of global partners, markets and brands along with the creation of domestic and international networks for collaboration.

C. India [13]

India's science, technology and innovation policy, 2013, is aimed at faster, sustainable and inclusive growth and sees innovation as a development driver. STI is a means to promote economic wealth, global competitiveness and social good. The policy stresses the importance of inclusivity in terms of the effect of innovation on "as large a population as possible." The policy emphasizes the importance of developing a "scientific temper" throughout society, among youth and from all social strata to position the country globally as a scientific power. In relation to youth, the policy highlights the need to improve R&D investments, rankings, facilities, infrastructure, activity and personnel. R&D activities will also focus on international and global participation. The policy promotes increased participation by females in STI activity. STI will play a role in mitigating the effects of climate change. The policy calls for academia-research-industry partnerships and mobility as well as interdisciplinary research and alliances with other countries.

D. South Korea [14,15]

South Korea's "Creative Economy" (CE) features Centers dedicated to the creation of employment and new industries. The Centers help start-ups and small and medium enterprises to globalize and act as creative hubs for commercialisation of ideas. The CE also features an 'ecosystem' to stimulate and simplify access to start-ups and ventures as well as support for access to global markets, overseas partnerships and recruitment of overseas' talent. Strengthening of future growth hinges on industry-academia-government collaboration. Other aspects of the CE involve nurturing creative talent and entrepreneurship and the creation of new industries through STI and information and communication technologies (ICTs). An entrepreneurial spirit of ingenuity and curiosity is encouraged. The CE promotes science, technology, engineering, arts and mathematics education in primary and secondary schools. The CE also aims to advance the country's culture and content industries and promotes collaboration and cooperation in terms of the integration of science, technology, ICT, industry, culture and the arts.

E. ASEAN [16,17]

The ASEAN plan (Action on STI 2016-2025) aims to achieve a competitive, sustainable and inclusive ASEAN. The plan is structured according to thematic tracks. The first of these revolves around raising the quality of life and contributing to competitiveness through developing capabilities to serve local and global markets. The second focuses on ICTs to develop a knowledge-based society. Track three relates to green technology and more environmentally-friendly production to mitigate and adapt to climate change to ensure sustainable development. Food and energy security and water management are the foci of tracks four, five and six respectively and emphasize safety standards, improvement, optimisation and efficiency. Track seven recognizes the need for biodiversity in relation to food, health and energy. The final track highlights the role of youth for ASEAN prosperity and capacity building. This track emphasizes the need for scientific literacy, technological competency, creativity, passion and lifelong learning realized through an innovative ecosystem in schools, vocational and higher-education institutions.

III. COMMON THEMES

This section of the paper presents results related to objective 2: Analyze common themes from the policies. Themes refer to the main intents of the policies. Inductive analysis of patterns, keywords, and terms in the policies presented in the previous section led to the emergence of seven themes: prosperity, humanity, inclusivity, capacity, sustainability, inquiry, and community. *Prosperity* serves as a central goal or purpose. It is manifested and articulated usually as socio-economic transformation and growth that results in a high-income, wealth, high-value, competitive and first-world, knowledge-based economy. A prosperous economy is one in which new employment and industries are constantly emerging. A prosperous nation is scientifically advanced and operates with smart technologies, robotics, ICTs, and automation. It has the competitive capability to serve both local and global markets. However, this prosperity is underpinned by an emphasis not merely on financial aspects but on human ones.

The category of *humanity* highlights the need for prosperity accompanied by social good, social security, well-being, and a higher quality of life. It is characterized by a society that is resilient and peaceful. Individuals in this society uphold ethical and humanistic values and are competent human beings and first-world citizens. Closely related to this category is that of *inclusivity* which represents both an outcome of and means to achieve prosperity. Innovation depends on and results in an inclusive society within which there is realization of the full potential of all members, reduction in social disparity, equitable access to prosperity and social opportunities and an unlocking of individual limitations. As emphasized in the policies, a key feature of inclusivity is the equitable and increased participation of females in society and the economy.

Realization of prosperity depends on a number of factors. One of the most important of these is *capacity* building. Capacity building is directly related to the quality and focus of education. It involves not only a focus on STEM but on the arts. In particular, capacity is achieved through higher levels of thinking and skills including creative and analytical. In addition, it involves development of ingenuity, entrepreneurial spirit, scientific literacy, technology competency, passion, risk-taking and lifelong learning. The capacity for innovation is grassroots-driven, from the bottom up. Entrepreneurial capacity is built through financial supports, creative hubs for commercialization of ideas, simplified access to start-ups and ventures, support for access to global markets and recruitment of overseas' talent and the nurturing, retention and use of talent.

Inquiry plays a central role in innovation and is achieved through an emphasis on and support for R, D&C activities. The R&D are not restricted to STI but include integration of social sciences and humanities research with sciences and interdisciplinary foci. The integration brings together science, technology, ICTs, industry, culture and the arts. Increasing the number of researchers, promoting private sector investments, improving university rankings, facilities, infrastructure, activity and personnel: these are some of the approaches to promoting inquiry that can lead to innovation. Most importantly, the inquiry takes place in a collaborative context. Innovation is achieved through collaboration, cooperation, alliances, networking, partnerships, through knowledge transfer and mobility of personnel. *Community* connects the domestic with international countries, their markets and institutions. It connects academia with industry and government. Finally, it is not enough to foster innovation. An emphasis on sustainability plays a key role in ensuring a balance between social and economic growth and development. It ensures that development is environmentally friendly and that it adapts to and mitigates the effects of climate change. It allows for a healthy society, livable cities and green nations Sustainability requires environmental protection and attention to standards, efficiency, optimization, security and management of essentials such as food, energy and water management.

IV. IMPLICATIONS FOR EEFI

This section presents results related to objective 3: Determine implications for approaches to EEFI. For each of the seven categories, sample pedagogical approaches are described from the literature.

A. Prosperity

To contribute to the realization of a high-income, prosperous country, EEFI should produce the human capital needed to lead and drive economic development through the creation of physical and digital infrastructure [18]. Knowledge-based economies depend on highly capable and qualified people and quality assurance has a role to play in ensuring the high level [19]. Prosperity can be driven by increasing the number of quality engineering graduates and supporting the creation of academies of engineering in countries where none exist. Longer (e.g., 5 year) programs compared to shorter technical programs as well as those with more spending are more likely to provide the professional qualifications needed for economic development [18]. A prosperous nation operates smart technologies, robotics, ICTs, and automation. Therefore, economies "will require a breed of engineers who are more literate in high-tech areas like nanotechnology materials engineering, and ICT" [18]. EEFI programs should aim to match the demand for skills in the economy with students' enrolments. For example, countries may find that while they are producing a large number of engineers, their skills may not correspond to what is needed [18]. The quality of programs should be monitored to ensure that engineers have the skills needed by the economy [18]. A nation's prosperity and power will also rely on a strong foundation in STEM education [21]. Engineers should have theoretical understanding yet be capable of practical application of that understanding [22]. Programs should offer interdisciplinary projects that integrate business, STEM and the social sciences [23].

TABLE 1. SUMMARY OF INNOVATION CATEGORY OF PROSPERITY

PROSPERITY
Human capital
High-quality programs/engineers
Quality monitoring & assurance
High technological literacy
Longer programs
Strong STEM foundation
Theoretical understanding & practical application
Reliance on advanced technologies
Skills matched to economy's needs
Increased number of graduates
Interdisciplinary projects
Well-funded programs

B. Humanity

The category of humanity signals the need for engineers to be more than merely technicians and is a reminder that engineers can and must play a pivotal role in bringing about changes in the very core of society. For engineers to adopt this role, EEFI needs to promote holistic learning. Holistic EEFI moves beyond STEM to engage learners in contextualized problem formulation and resolution, multi-disciplinary thinking and global awareness so that engineers can lead change and devise solutions to the increasingly complex and uncertain challenges facing societies [24]. Use of reflective journals can help focus students' attention on professional responsibilities and ethics [25]. Graduates need a reflective and an ethical dimension to their learning to enable them to lead and mange social change [6]. They must learn to deal with ambiguity inherent in social contexts and be able to contribute to policy [6]. EEFI programs should help students develop a capacity for divergent thinking to be able to see the outcomes of what engineers do through the perspectives of those who are not engineers [26]. They should develop professional judgment of the impact of their decisions [22]. Ethics can be integrated into programs through activities that focus on the code of engineering ethics such as public safety, environmental protection, honesty, fairness, and on the benefits and potential harm of technology and development [27]. Courses should move beyond STEM to include the liberal arts in order to better prepare graduates for real-world problem solving [20].

TABLE 2. SUMMARY OF INNOVATION CATEGORY OF HUMANITY

HUMANITY
Holistic learning
Ethical & reflective graduates
Divergent & multidisciplinary thinking
Courses in the liberal arts
Professional responsibilities and ethics
Real-world, contextualized problem solving
Global awareness
Able to deal with ambiguity & contribute to policy
Leaders and mangers of social change
Able to judge impact of their work

C. Inclusivity

Inclusive EEFI programs might invite, allow and support participation from individuals regardless of gender, disability, faith, socio-economic status, political or sexual orientation, race, ethnicity or culture [28]. Opportunities for students to collaborate internationally can help prepare them for an increasingly global world. Inclusion may be promoted by affirmative action efforts [28]. 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 EEFI programs must be accompanied by efforts to retain them [29]. These efforts can include normalizing 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 [29]. Inclusion also involves diverse faculty in programs with proactive measures to attract, for example, female faculty members [29] and to provide them with opportunities to reach tenure and to occupy positions in upper-level administration [28]. Mentors can also support and help develop a sense of belonging among marginalized members while cultural sensitization and development of cultural competence and socio-emotional sensitivity can help with retention [28]. EEFI programs can also facilitate and encourage collaboration with minority and underrepresented groups [30].

TABLE 3. SUMMARY OF INNOVATION CATEGORY OF INCLUSIVITY

INCLUSIVITY
Equitable inclusion of people in programs
Affirmative action
Development of cultural competence
Development of socio-emotional understanding
Use of mentors
Hospitable programs
Equitable inclusion of people in programs
Affirmative action
Efforts to include & retain under-represented groups
Diverse faculty including females
Diverse experiences for diverse learners.
Minority representation in administrative positions
Collaboration with under-represented groups
Increased inclusion of female learners
Hands-on experiences

D. Sustainability

Forms of learning that can promote sustainability include experiential and community-based learning [31] and pedagogies of engagement in which students are active and engaged in the learning process [32]. EE students may benefit from involvement with Engineers without Borders, problem-based learning projects in which they work in teams to identify community needs and implement solutions [33]. EE programs can provide opportunities in the curriculum for greater global awareness projects and activities that involve social engagement and social justice such as community-development work [34]. UNESCO's report on challenges facing engineering noted the need for forms of EE that de-emphasize formulaic learning and emphasize 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 [29]. EE programs can offer specialization in EE for sustainable development (EESD) as flagship courses, lunch-time seminars, guest lecturers, full degrees, and can ensure that they have faculty who are well-versed in EESD [29]. 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 [35].

TABLE 5. SUMMARY OF INNOVATION CATEGORY OF SUSTAINABILITY

SUSTAINABILITY
Experiential learning
Identify community needs & solutions
Social engagement & justice
De-emphasis of formulaic learning
Focus on real challenges, ethical & global issues
Project & problem-based learning
Global awareness & responsibility
Knowledge of global issues
Engineers without borders
Courses, seminars, guest lecturers
Active & engaged learning
Systems' thinking

E. Capacity

Capacity building can be achieved through inductive teaching methods that use authentic problems and that promote learner-centered construction of knowledge rather than knowledge transmission [36]. Building capacity also means giving students the opportunity to think meta-cognitively, analytically and in creative ways so that they can better solve real-world problems. Approaches to developing students' creative thinking capacity include open-ended projects without pre-defined targets, support for and encouragement of risk-taking, and opportunities to generate ideas and to engage in metaphorical thinking [37]. Capacity can also be built through an emphasis on lifelong learning [38], and by building strong technological literacy skills into the curriculum. EEFI should foster deliberate opportunities for awareness of the diversity of solutions to open-ended problems, for creative and divergent thinking and creative skills should be assessed [39]. Opportunities should be included to help engineers build awareness of the repercussions for business of their designs [22] and to understand the entrepreneurial mindset through experiential opportunities as well as opportunities for healthy competition [40]. Effective problem solving can also be fostered through a foundation in the liberal arts [41].

TABLE 4. SUMMARY OF INNOVATION CATEGORY OF CAPACITY

CAPACITY
Inductive teaching methods
Lifelong learning
Knowledge construction
Opportunities for healthy competition
Experiential opportunities
Entrepreneurial mindset
Liberal arts foundation
Awareness of consequences of engineering designs
Authentic problems
Learner-centered instruction
Analytical, divergent, metaphorical, meta-cognitive & creative thinking
Strong technological literacy skills
Encouragement of risk-taking
Open-ended projects & problems
Assessment of creative skills

F. Community

Community in EE has been made easier through the use of online technologies that allow for anytime, any-place, organizationally, culturally and geographically diverse communication and collaboration. Internships and work placements provide opportunities for students to collaborate with diverse groups of individuals and with specialists from varying fields. Students can be provided with long- or short-term opportunities to apply their knowledge and skills in government and in industries or firms that operate internationally. Moving away from the 'chalk and talk' lecture methods that have dominated EE, learning can engage students in project-based teams [39]. Teams should develop positive interdependence and accountability as well as positive peer relationships [32]. Community can be built through senior students mentoring and leading new students [33]. However, it is not enough to provide opportunities for community on its own, rather students need to learn how to communicate effectively, develop interpersonal skills, resolve conflict, share decision making and show accountability to each other [42].

TABLE 6. SUMMARY OF INNOVATION CATEGORY OF COMMUNITY

COMMUNITY
Teams with varied skill sets
Internships & work placements with diverse groups in industry & internationally
Project-based teams
Development of communication, interpersonal & conflict management skills
Anytime, anyplace, virtual communication & collaboration
Seniors mentoring & leading juniors
Shared decision-making & accountability
Positive peer relationships
Collaboration with specialists
Application of knowledge & skills in real contexts

G. Inquiry

Engagement in inquiry relies on students investigating problems and questions and on observing and explaining phenomena [43]. Students can engage in discovery learning whereby they seek responses to questions and solve complex problems [36]. Inquiry can take place in the context of problem- and project-based learning in which students build and apply content-specific knowledge. Such inquiry involves students formulating research questions related to the problem, conducting literature reviews to determine what is already known about the problem and subsequently collecting and analyzing data. Students can engage in inquiry in physical or virtual laboratory settings, the latter being particularly relevant for unobservable phenomena and where safety would be an issue in a real versus simulated context [44]. Research by students in real contexts can involve gathering information about the needs of a particular community and subsequently implementing engineering designs related to those needs [44]. Inquiry-based learning, like project and problem-based, requires active participation and engagement in higher-order thinking skills. Inquiry can provide a means to test, contextualize, better understand theory and to see its real-life implications. Providing students with opportunities to conduct research, even on a small scale, can help move the curriculum away from an emphasis on content transmission and on 'knowing how and what' towards an emphasis on knowledge construction and building and on 'knowing why.'

TABLE 7. SUMMARY OF INNOVATION CATEGORY OF INQUIRY

INQUIRY
Investigating complex problems & questions
Discovery learning
Formulating & seeking responses to research questions
Collecting & analyzing data
Gathering information regarding community needs
Analytical, & evaluative thinking
Emphasis on knowledge construction & knowing 'why'
Implementing designs in real contexts
Observing and explaining phenomena
Building & applying context-specific knowledge
Conducting literature reviews
Using physical & virtual laboratories
Active participation & engagement
Testing, contextualization & real application of theory
Context specific knowledge
Problem- & project & inquiry-based learning

V. A MODEL OF ENGINEERING EDUCATION FOR INNOVATION

This section presents results related to objective 4: Create a model of EE for Innovation (EEFI). The model is organized according to four bases and seven outcomes. The bases are STEM + AE, quality, learners and problems and projects. The outcomes are prosperity, humanity, sustainability, inclusivity, capacity, inquiry and community. The model offers a coherent and comprehensive framework for understanding EEFI. Each of these bases is described in this section.

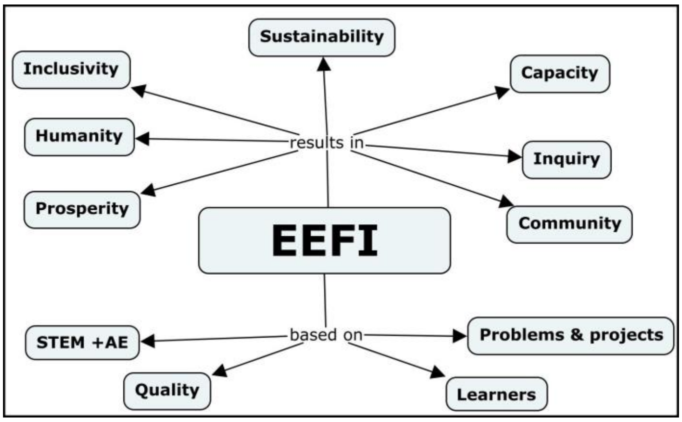

Fig. 1. EEFI Model

A. STEM + AE

STEM + AE refers to a base of science, technology, engineering and mathematics as well as the arts and entrepreneurship. This base includes learners' engagement in high-order thinking as they build and apply theory, knowledge and skills. Fig. 2 summarizes the STEM + AE base of the EEFI model.

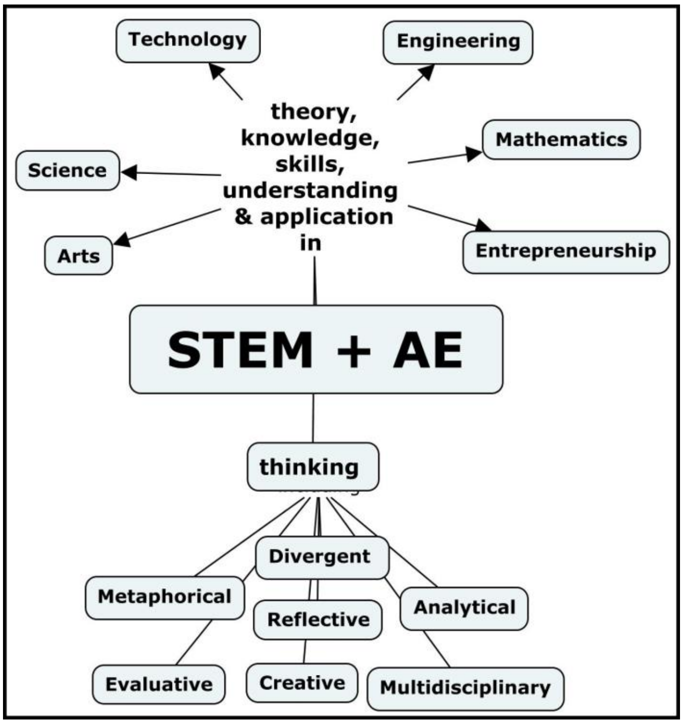

Fig. 2. Summary of the STEM + AE base of the EEFI model

B. Quality

Quality draws attention to fundamental and underlying efforts to ensure the best in terms of the program and its graduates. It highlights policy issues such as the length of programs, how well they are funded and how relevant they are for the economy. Quality also pertains to policies and strategies that ensure diversity and inclusion, not only in relation to the gender of faculty and learners but in terms of inclusion of minorities and underrepresented groups. Fig. 3 summarizes the base of quality in the EEFI model.

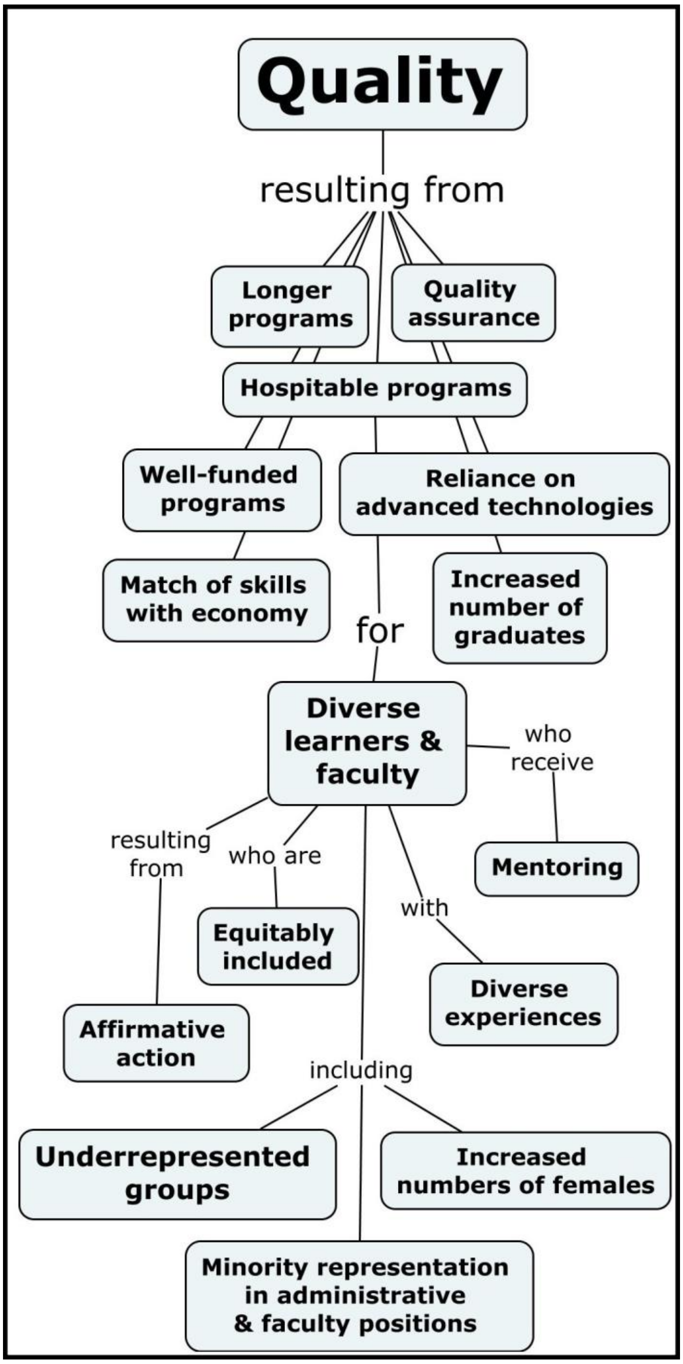

Fig. 3. Summary of Quality base of the EEFI model

C. Learner

The learner base is a reminder that EEFI involves learning what it means to be an engineer as much as it is about how to be an engineer. This base is about the characteristics, competencies and attributes of learners. Fig. 4 summarizes this base of learners in the EEFI model.

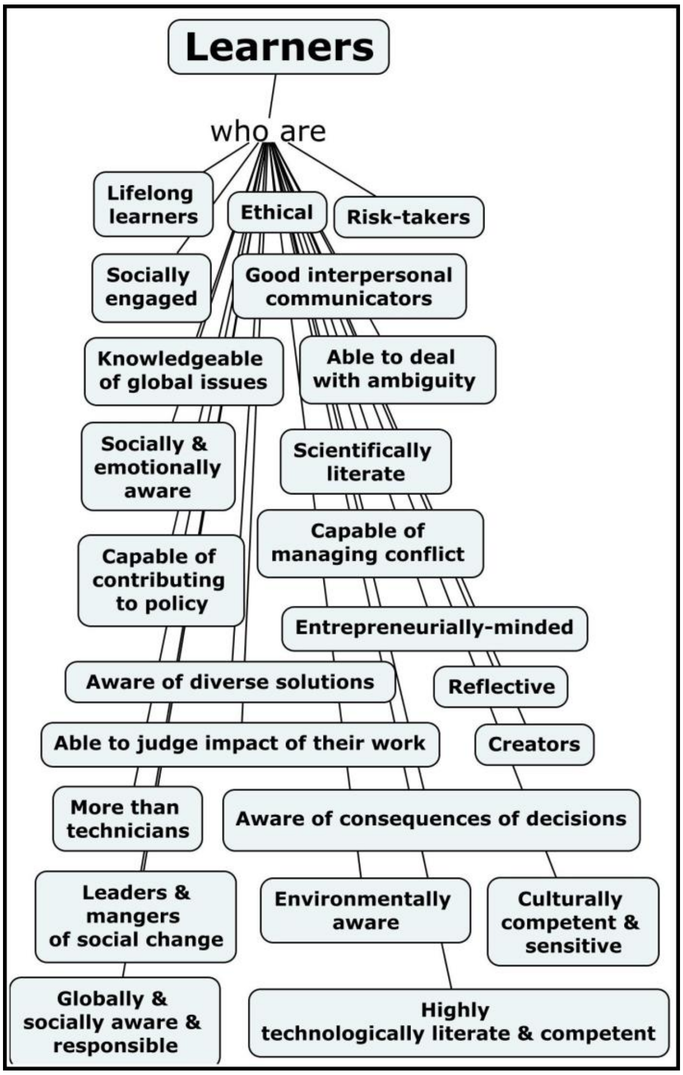

Fig. 4. Summary of the learner base of the EEFI model

D. Problems & projects

The bases of problems and projects drive activity in learning. The problem and project bases ground learning in real community contexts. The bases give purpose to learners' activity and support application of understanding of theory into practice.

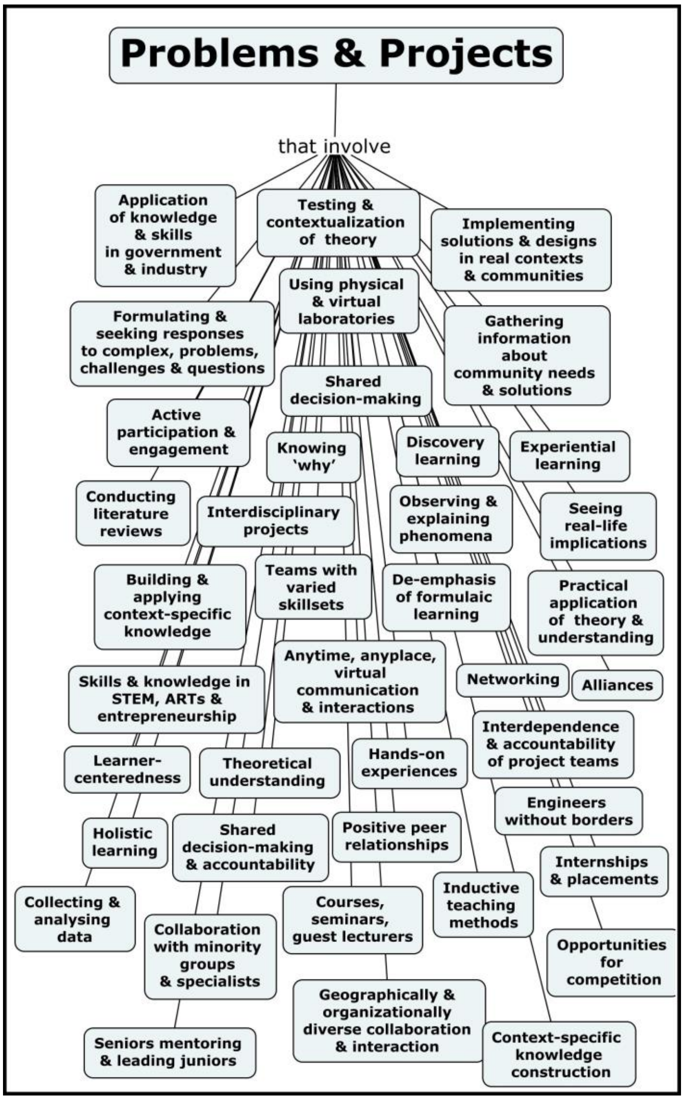

Fig. 5. Summary of the Problems & Projects base of the EEFI model

V. IMPLICATIONS FOR EEFI RESEARCH

This section presents results related to objective 5: determine implications for EEFI research. In general, research in EE has tended to favor quantitative approaches [45]. Quantitative approaches often rely on conducting surveys using Likert-type items with EE students or faculty and subsequently calculating frequencies. For example, students at an American university completed a survey that inquired into their knowledge of, interests in, conceptual and applied understanding of and professional choices related to sustainability as well as the contribution of curricular and extracurricular activities to their learning [46]. Another approach that involves quantitative data is that of intervention studies with experimental versus control groups using pre- and post-tests alone or with quantitative surveys such as those that measure satisfaction.

The focus on quantitative methods is in spite of the fact that qualitative methods have much to offer engineering education, both in terms of answering more complex questions and providing rich data [47]. A qualitative approach to the study of innovation in EE can more easily and accurately capture the complexity of context, (e.g., the classroom or institutional culture), than can a quantitative experimental study that merely aims to demonstrate the effectiveness or lack thereof of an intervention [45]. Qualitative data may be generated by many different data collection techniques including focus groups, interviews, student-journal reflections, observations or open-ended questionnaires. Qualitative research can be conducted using various methods such as case studies, ethnographies with participant observation, or use of phenomenology to understand lived experiences.

In terms of researching EEFI, quantitative approaches using surveys can provide data related to EE students', faculty's or industry's perspectives on any or all of these categories. Surveys can be combined with more qualitative and iterative methods to provide more holistic and in-depth insights into phenomenon. As an example, a study of engineering teams with international students relied on both surveys and focus groups [48]. The study investigated differences between the experiences of international student teams versus the local UK and European union teammates. An initial survey was completed by 108 students. The survey included both closed and open items which meant that data were subsequently analysed quantitatively and well as qualitatively to identify themes in participants' additional comments. Results of analysis of the survey then informed the focus groups for 22 international students from the original 108. In addition, students entered peer and self-assessment feedback into an online system that was analysed and that compared for international students the two types of feedback. Finally, there was an online survey for the international students designed based on analysis of previously collected data. The survey was analysed quantitatively and compared in terms of themes with previous data. The researchers presented their findings both quantitatively and thematically. Based on the results, the researchers subsequently proposed interventions to promote more equality for the international students. A follow-up study with surveys and focus groups were planned that would investigate the effect of these interventions to ensure that program graduates are "internationally sensitive, globally competent engineers" [48].

In another study, [49] the researcher used an interpretivist research paradigm to investigate issues of inclusivity in relation to gender in an EE program. The researcher described her approach as a theory-building case study in one institution. The purpose of the study was to determine if the culture of EE in the institution resulted in an inclusive culture. Data were collected over a four-year period and included a questionnaire for final-year students of various ethnicities (all females and 100 males) of their perceptions of their academic and social experiences and of possible gender differences. There was also a questionnaire for staff related to perceptions of gendered differences as well as access to student evaluations of their course experiences. Other forms of data collection included semi-structured interviews using open-ended questions with staff and with graduates and first-year students. First-year students also participated in focus groups. The researcher then conducted participant observation using field-notes of activities such as lectures and workshops. Additionally, the case study data included artefact and documents such as mission statements and governance documents. Data analysis was iterative and led to themes and categories.

A study by Thai students in a Bachelor of Science in Industrial Education (majoring in civil engineering) and a doctoral candidate [44] reflects many elements in the EEFI model. The students themselves were researchers and conducted their study as part of a course that engaged them in problem- and project-based learning. Over an eight-week period, the students collaborated with community members, with each other and with external evaluators who provided feedback on the project. Students first collected and analysed data in a village that was using an early warning system for landslides that had been previously been installed by a Japanese company. Next, they assessed community members' math skills and their understanding of the system. To teach members about the system and about how to calculate the time needed for evacuation, students created a model of the system and relied on pre- and post-tests and activity sheets. In addition, they assessed community members' satisfaction with the project. The doctoral candidate who was also the principal investigator subsequently disseminated the results of his inquiry through publication in an academic journal.

VI. CONCLUSIONS AND LIMITATIONS

This paper was limited to a focus on innovation in Asian countries and, within that context, explored the policies of four countries in addition to the ASEAN policy. The relationship between innovation and EE programs and research may manifest itself differently in other parts of the world and given other types of policies. However, Asia provides one case in which to explore the implications of innovation. Both the consideration of implications for education and research suggested that EE has been characterized by ways of doing that are anchored in tradition. That tradition contrasts with the exigencies of innovation that call on institutions to evolve in response to local and global changes in society and the economy. Thus, innovation presents an opportunity and impetus for EE programs and research to adopt new ways of doing. Likewise, innovation challenges EE programs and research by demanding that they evolve in order to remain viable and relevant.

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