A Taxonomy of Engineering Attributes for Tackling Humanitarian Challenges

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***Abstract*—There is a growing interest in enabling competences such as creativity, critical thinking and problem solving to engineering students by expanding their engagement to complex, interdisciplinary problems linked to global humanitarian challenges. A skills gap seems to be exacerbated, especially in emerging economies, with an over-reliance on multinational organisations and temporary, non-domestic workforces, limiting the provision for development of in country capacity to apply engineering safely. Tackling humanitarian challenges requires knowledgeable and erudite engineers who can handle, combine, transform and create innovative, affordable and sustainable solutions. This view simultaneously complements and challenges current concepts of an emerging educational movement that, almost without exception, are underpinned by calls for competitive economic growth and technological development. This article reveals a taxonomy of humanitarian attributes to be enabled to professional engineers, through reformed curricula and innovative learning strategies, which once implemented and integrated efficiently in higher engineering education, they shall provide students and educators with opportunities to explore interdependencies and links between traditional engineering attributes with skills such as leadership and social influence, international awareness, sustainability, emotional intelligence, professionalism, cultural sensitivity and ethics, and to critically engage with implicit and explicit facets of other disciplinary identities. Within the framework of the study presented herewith, qualitative research was carried out through three practice dialogue workshops, run in Asia (Vietnam, Indonesia and Bangladesh) involving a variety of national, international and local stakeholders (industries; NGOs; governmental organisations).**

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I. INTRODUCTION

There is a growing interest in enabling competences to graduate engineers such as creativity, critical thinking and problem solving by expanding their engagement to complex, interdisciplinary problems linked to global humanitarian challenges [1]. A skills gap seems to be exacerbated, especially in emerging economies, with an over-reliance on multinational organisations and temporary, non-domestic workforces, limiting the provision for development of in country capacity to apply engineering safely [2].

The article focuses in the Asian region, the most adversely affected region by humanitarian challenges. Asian Countries suffer from combined:

- increased vulnerability to humanitarian challenges (e.g. 15 million people displaced by natural disasters in Philippines; Malaysia is ranked as the most hit country by floods in the region; in the 2004 tsunami that hit Indonesia, women accounted for 77 percent of deaths; Vietnam is battered every year by up to 10 storms, killing hundreds or even thousands of people etc.) [3], [4]; and,
- most inefficient engineering education provision [5], [6].

Traditional educational models of artificial separation of knowledge, disciplines and skills seems to be no longer relevant. Many engineering programmes, in the world and especially in emerging economies [5], provide education using mainly traditional curricula and learning strategies with students relying on memorisation and repetition of information, having minimum relevance to real-life problems and global challenges. Reformed curricula and active learning environments should be utilised for developing skills such as leadership and social influence, international awareness, sustainability, emotional intelligence, professionalism, cultural sensitivity and ethics [6]. There is need for introducing the integrated interdisciplinary nature of knowledge as central to creativity and innovation against emerging global challenges – one cannot think in silos and be meaningful in a knowledge economy [7].

The study presented in this article was conducted in the framework of the project ENHANCE- ENabling Humanitarian Attributes for Nurturing Community-based Engineering (project No: 598502-EPP-1-2018-1-UK-EPPKA2-CBHE-JP (2018-2582 / 001-001), funded by the Erasmus + KA2 Cooperation for innovation and the exchange of good practices – Capacity building in the field of Higher Education. This is a 3-year collaborative multi-partner project, listing 9 partner Higher Education Institutions from UK, Greece, Vietnam, Indonesia and Bangladesh. The project is coordinated by the University of Warwick (UK).

II. BACKGROUND AND RATIONALE

According to the Asian Development Bank reports [4], [5], [6], [8], major constraints in Higher Education (HE) in the Asian region are summarized as:

- Absolute lack of innovative and creative strategies in HE, for accelerated human resource development. Hardly any innovative pedagogical approaches in engineering education programmes. Traditional methods of instruction, examination, and student evaluation. The traditional model of artificial separation of knowledge, disciplines and skills seems to be no longer relevant. Universities provide education using mainly traditional methods, such as lectures and the evaluation of students through written examinations, with hardly any modern methods like: case analyses; presentations; group work; simulations; business games; term paper writing; formative assessment (including quizzes). There is need for introducing the integrated nature of knowledge and understanding, as it is applied in an everyday context to be central to creativity and innovation—one cannot think in silos and be productive in a knowledge economy.
- Extensive lack of technical and soft skills, ineffective and unsustainable training for safe humanitarian interventions and ignorance of existing skills' gaps; lack of skills gaps surveys; shortfall of engineering graduates projected to increase in the next decade [5], [9], [10], [11].

In response to the aforementioned, and according to what Boston Consulting Group [1] recommends, to help close the skills gap, action must be taken in shaping engineering curricula to promote creative, interdisciplinary, rigorous, less siloed curricula and learning strategies. Moreover, there is need to endorse innovative pedagogies to ensure that tools utilized by educational providers are of the highest quality.

Driven by common recognition that one way to address humanitarian challenges is through reformed curricula and innovative learning strategies, the authors have undertaken a detailed study on the required professional attributes (knowledge, skills, and experience) as defined by a number of varied stakeholders (academics, industry professionals, practitioners). The study involved identifying ways to integrate other disciplines and professions to engineering education while defining the professional attributes of engineers who are capable of tackling humanitarian challenges. The attributes are linked to discipline(s) and profession(s) that are more likely to enforce them (removing the assumption that engineering education as it stands at the moment can provide all of the required attributes). Further study was taken to capture the stakeholders' perception on how the required attributes can be supplied; what kind of learning settings and environments shall be introduced beyond current practices.

III. METHODOLOGY

The methodology for carrying out the study involved qualitative research through four practice dialogue workshops, run in Asia (Vietnam, Indonesia and Bangladesh) involving a variety of national, international and local stakeholders (industries; NGOs; governmental organisations). In total 90 participants have been consulted; 30 participants from each country allocated into groups of 5 members each with 60% of each group being male and 40% female participants.

The sampling was purposive. The participants were invited by the project researchers, to ensure the diverse and interdisciplinary, inter-professional sample that is needed to answer the research questions. The sample was such to ensure that the intended benefits of ENHANCE reach the local stakeholders (industries; NGOs; governmental organisations etc.) who should be able: (a) to influence and shape the engineering curriculum and the models of engineering education in order to produce the talent needed; (b) to develop effective graduate engineering programmes; (c) to contribute real problems and projects for students to solve and realise solutions to the community's real-life problems. Table I sets out the type of participants and number of participants per type for each group. All participants were over the age of 18, from the host countries (UK, Bangladesh, Indonesia and Vietnam).

TABLE I. COMPOSITION OF GROUPS

Type of participant	Number
Academia	15
Industry professional	5
Governmental Organisation	5
Non-Governmental Organisation (NGO)	5

The workshops took place at the premises of partner Universities; Ho Chi Minh City University of Technology (Vietnam), Gadja Mada University (Indonesia) and University of Dhaka (Bangladesh).

Prior to the beginning of each workshop the participants were orally informed about the topic of debate and were given hard copies of a participant information leaflet to read carefully for 10 minutes.

The participants, prior to the start of the session, were informed that the data are anonymised and kept confidential, and they are not going to be named in any report or publication. They were given to fill in a written consent form and they were allowed to withdraw at any time during the research activity.

Ethical approval was granted to the activities described herewith by the University of Warwick's Biomedical and Scientific Research Ethics Sub-Committee (REGO-2019-2341).

Each practice-dialogue workshop lasted 3 hours. Participants were asked to answer a set of questions as given in Table II. Formal anonymous feedback were elicited.

IV. COLLECTED DATA AND DISCUSSION

Participants were asked to answer a set of questions as given in Table II. Formal anonymous feedback were elicited.

TABLE II. QUESTIONS OF PRACTICE-DIALOGUE WORKSHOPS

No	Question
1	Complex problems, such as humanitarian challenges, are best solved by drawing upon many disciplines and multiple professions. Provide 3 arguments for and 3 arguments against this statement.
2	Is there a barrier to interdisciplinary inter-professional education?
3	What is your opinion on the capability of graduate engineers in solving complex problems?
4	What are the attributes (skills, knowledge, experience) that need to be developed in graduate engineers?
5	How do you think these attributes could be supplied?
6	What support can industry and other stakeholders provide to academia in delivering innovative interdisciplinary curricula?

The collected data are presented and discussed in the sections below.

A. *Complex problems, such as humanitarian challenges, are best solved by drawing upon many disciplines and multiple professions. Provide 3 arguments for and 3 arguments against this statement.*

From the practice-dialogue workshops in all three Asian Countries, there was consensus and appreciation that drawing upon many disciplines and multiple professions when tackling a complex problem, such as the humanitarian ones, stimulates effective cooperation within groups, systematic problem-solving approach, optimised acquisition and application of knowledge and efficient problem management.

Efficiency seems to be one of the main reasons for drawing upon multiple disciplines, mainly with respect to time but also to resources. A large number of participants, across all three Countries, gave quality of solutions as their second argument for; by integrating multiple disciplines, the solutions to complex problems would be more creative, bring more skills and a variety of perspectives and experiences to the design of solutions. A third argument for seems to be based on accuracy: drawing on multiple disciplines would reduce the presence of biases in crafting certain policies or solutions, or ways of looking at the problem, as well as securing more accurate and appropriate solutions.

TABLE III. ARGUMENTS FOR AND AGAINST INTERDISCIPLINARY, INTER-PROFESSIONAL COLLABORATIONS

Country	Arguments for	Arguments against
Vietnam	#1 Efficiency with regards to time, resources and solutions	#1 Difficulties in management and organisation
	#2 Optimised, comprehensive and creative solutions	#2 Waste of time in reaching agreement/conclusions
	#3 Accuracy in terms of enhanced collaborative working	#3 Conflict of interest within teams
Indonesia	#1 Disciplines complementing each other	#1 Complexity due to different perspectives and vision
	#2 Efficient and creative solutions to problems	#2 Time consuming processes
	#3 Accuracy in terms of enhnaced collaborative working	#3 Management and leadership difficulties
Bangladesh	#1 Different perspectives	#1 Conflicting opinions
	#2 Holistic approach to solutions	#2 Time consuming processes
	#3 Optimisation of resources (human and other)	#3 Solutions might be difficult to be implemented if too complex

On the arguments against, a large of responses suggested that time would be wasted, primarily in mastering different

skillsets or reaching an agreement/solution/conclusion, hence delayed decision making. The second most common argument against this approach was the underutilisation of skills and knowledge. Others called this a "shallowness" in the disciplines. Other comments included lack of passion in non-specialised disciplines, conflicts of interests and difficulties in organisation.

Table III summarises the 3 arguments for and 3 arguments against (in order of preference from highest to lower) solving humanitarian challenges by enabling interdisciplinary, inter-professional collaborations.

B. Is there a barrier to interdisciplinary inter-professional education?

Participants were asked to indicate whether barriers exist in the current HE practices and structure that prohibit interdisciplinary inter-professional education.

The most pressing barrier that was perceived by the participants across all three Countries was communication issues; these were mainly rooted in differences in terminology or use of jargon across the disciplines and professions, which could lead to misunderstandings or misinterpretations. Another barrier was conflicts of interest, especially those that arose from the different disciplinary perspectives and perhaps confusion of the overlaps. Resources were also perceived to be a possible barrier, such as human resources, time and money. Moreover, the discussion in many groups evolved around the question of how interdisciplinary inter-professional educational programmes would be taught and the approach to teaching which would differ significantly from current traditional practices.

In summary, across all practice-dialogue workshops the following barriers have been identified:

- The present education system in Asia does not encourage interdisciplinary learning due to lack of collaborators with interdisciplinary mindset and experience from academia, industry and other stakeholders;
- Academics are stuck to disciplinary research and teaching (disciplinary egocentrism) without being open and flexible enough to embrace interdisciplinary activities and inter-professional collaborations;
- Lack of resources (human, facilities) from the HE Institutions that could enable a shift in education towards creative, innovative teaching and learning approaches.

C. What is your opinion on the capability of graduate engineers in solving complex problems?

The participants were asked to evaluate the capability of graduate engineers in their Country, in solving complex problems such as humanitarian challenges. The responses to this question, per Country, are given in Tables IV-VI.

TABLE IV. VIETNAM: STRENGTHS AND WEAKNESSES OF GRADUATE ENGINEERS

Vietnam	
Strengths	Weakness
Open attitude to learning	Lack of experience in solving real-life problems
Analytical skills	Difficulty in team working
Theoretical knowledge	Weak communication skills directed to technical and non-technical audiences
IT skills	Lack of interdisciplinary perspective

TABLE V. INDONESIA: STRENGTHS AND WEAKNESSES OF GRADUATE ENGINEERS

Indonesia	
Strengths	Weakness
Experience in community-based activities	Lack of experience in solving real-life problems
Analytical and technical skills	Weak communication skills directed to technical and non-technical audiences
Theoretical knowledge	Lack of comprehensive understanding considering social and other aspects (e.g. ethical, cultural)

TABLE VI. BANGLADESH: STRENGTHS AND WEAKNESSES OF GRADUATE ENGINEERS

Bangladesh	
Strengths	Weakness
Theoretical knowledge	Lack of critical thinking
Teamworking skills	Lack of practical and field experience
Communication skills directed to technical and non-technical audiences	Lack of interdisciplinary perspective
Problem-solving skills	Little exposure to community problems
Analytical and technical skills	Difficult to adapt to new working environments

According to the collected data, weaknesses to the skills of graduate engineers in the three Asian Countries are mainly related to collaboration, networking, agility and adaptability, effective oral and written communication, and last but not least exposure to real-life problems and applications.

The aforementioned skills were distinguished from the participants from technical, or 'hard skills' where the graduates in the three Asian Countries seem to be strong and confident with. As soft skills are applicable and useful in various contexts, the participants have expressed their appreciation that these skills can be supposedly developed or transferred among different professions and disciplines.

With regards to interdisciplinary inter-professional awareness, the study demonstrated that: (1) graduates seem to be unable to recognise the relationship between their own discipline and other disciplines, and; (2) graduates cannot value the contributions of multiple technical and non-technical perspectives to a given interdisciplinary problem.

D. What are the attributes (skills, knowledge, experience) that need to be developed in graduate engineers?

In this question, there has been a consensus from the participants over all three Countries that highly qualified and employable engineers must have strong theoretical knowledge combined with critical thinking, communication and teamwork skills, problem solving, creativity and entrepreneurship. Agility, adaptability, open mindset and empathy have been also identified as key attributes for the engineers of 21st century.

To this respect, graduate engineers are expected to be able to:

- identify contributions that new arenas of knowledge can make to their own disciplinary expertise;
- identify ways in which their disciplinary expertise can contribute to the solution of interdisciplinary problems;
- identify the value and contributions of other areas of expertise to a particular interdisciplinary challenge;
- synthesize both concepts and approaches from multiple domains to develop an integrated solution to a given interdisciplinary challenge.

E. *How do you think these attributes could be supplied?*

The participants considered initially a range of traditional teaching and learning activities for supplying the needed attributes as previously identified. In particular, analytical skills were thought to be most widely developed through small-group teaching such as seminars and tutorials. Leadership skills were mentioned more often in relation to project/problem-based learning, practical and field activities.

Lectures and example classes were cited as the most effective approaches for developing problem-solving skills. On aggregate, seminars, community-based activities, field and practical activities seem to develop most of the needed skills, whilst self-directed study is perceived as less beneficial for skills development. Nevertheless, self-directed study is still thought to be rather effective at developing critical thinking skills as any of the other methods, and the same appears true for analytical skills and creativity.

Throughout the workshops interesting discourses took place around the need to introduce innovative learning environments by incorporating to graduate engineering programmes: (a) interdisciplinarity by bringing together unique expertise from multiple disciplines - enabling students to approach problems from a holistic perspective; (b) student as producer of knowledge, as opposed to being passive receiver of information; (c) open space learning which puts students on the same level as the expert by encouraging them to see themselves as co-creators in new knowledge and understanding.

The participants had the opportunity to challenge the traditional 'lecture' paradigm that can create passive receivers of knowledge, by constructing an environment where the application and synthesis of new knowledge with own unique understanding is fundamental.

The study further demonstrates that these attributes can be developed by incorporating in engineering curricula aspects of different disciplines. It appears that problem solving, creativity, critical thinking, and communication skills are most widely shared skills by all disciplines. The study reported that engineering or medical/health sciences fail to cultivate cultural sensitivity. The participants appreciated that engineering curricula could seek to incorporate aspects of social sciences for strengthening international awareness, ethical awareness, prioritisation, empathy and culture sensitivity. From sciences, the engineering curricula could benefit towards developing problem solving, critical thinking and analytical skills and from business sciences could benefit in developing leadership, social influence, communication, networking and prioritisation skills. By incorporating facets of arts and humanities to engineering curricula, students can be equipped with emotional intelligence, culture sensitivity and empathy.

F. *What support can industry and other stakeholders provide to academia in delivering innovative interdisciplinary curricula?*

Fig. 1 shows the perception of the participants on how industry and other stakeholders could support academia in delivering innovative engineering curricula.

There seems to be consensus across the three Countries that research collaboration and funding, opportunities to experience the workplace and exposure to real-life applications and problems are the most impactful contributions.

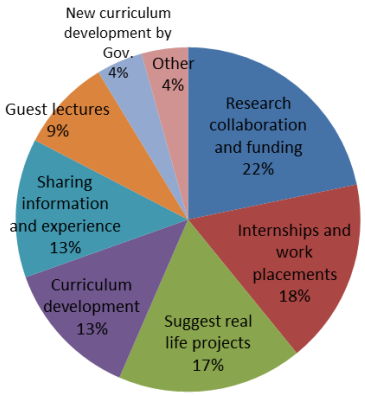

Fig. 1. Support from industry and other stakeholders to the delivery of engineering programmes.

The study revealed the need for HE Institutions to engage in a productive and meaningful manner with industry by introducing an industrial advisory board for each engineering programme and engaging to industry mentor training schemes, as means of guidance on curriculum development and content, student continuing professional development and research activities.

V. CONCLUSIONS

Findings from the study provide evidence that interdisciplinary, interprofessional discussions within engineering curricula can be productive, with stakeholders expressing their willingness to support rigorous, less siloed curricula and learning strategies. Within the framework of ENHANCE, the partner HE Institutions in Vietnam, Indonesia and Bangladesh will modernise and refresh engineering programmes to incorporate interdisciplinary, inter-professional teaching and learning strategies.

Attributes such as leadership and social influence, international awareness, sustainability, emotional intelligence, professionalism, cultural sensitivity and ethics develop by critically engaging engineering curricula with implicit and explicit facets of other disciplinary identities (humanities, arts, science, social science).

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