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A Retrospective Look at Sustainability and Engineering Education

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***Abstract*—While the term *sustainability* in engineering education has been in use for more than three decades, engineering institutions have been lax in understanding how to incorporate sustainability as an integral part of engineering lexicon. This paper takes a retrospective look at the important issues from the ground up – the challenges facing engineering institutions including accreditation and curriculum reform, the myths surrounding sustainability, engineering education and climate change, and what can and should really be done to make undergraduate engineering education play a crucial role in solving the enormous problems faced by society brought about by unsustainable practices. Contrary to popular belief, there is an important role for <u>all</u> engineering disciplines to play in solving societal problems.**

***Keywords*—Engineering education; sustainability; climate change; Grand Challenges.**

***JEET Category* — Op-Ed.**

I. INTRODUCTION

SUSTAINABILITY is sometimes a misunderstood word and often, one whose definition is in the eyes of the beholder. The Oxford dictionary defines the word as "avoidance of the depletion of natural resources in order to maintain an ecological balance". Back in 1987, the Brundtland Commission report [World Commission on Environment and Development, 1987] defined the word as "meeting the needs of the present generation without compromising the ability of future generations to meet their needs". In the institution where I learn and teach, sustainable engineering is explained as follows: Sustainable engineering is a revolutionary approach to engineering that

- Focuses on the long-lasting improvement of the human condition;
- Recognizes the connections between infrastructure and the human and natural systems; and
- Designs and constructs complex systems by considering environmental impacts, life-cycle assessment, and risk and uncertainty, along with technical and economic effectiveness.

Furthermore, "the built environment includes society's physical infrastructure and integrated systems that create the conditions for sustained health, prosperity and social well-being.", and "Involvement with the built environment generally includes the initiation of projects or programs through planning, design, construction, operations, and decommissioning; the so-called "life-cycle" of the endeavor." Rather than engage in unproductive discussions on how to define the term, my definition is simple – "Sustainability is like pornography; you know it when you see it"[1].

The paper is divided into three major sections. In the next section, both sustainability and engineering education are addressed. Often, complex topics have their fair share of myths, and some of the myths associated with sustainability are enumerated in Section III. The task of integrating engineering education and sustainability is addressed in Section IV. Finally, the paper concludes with an assessment of sustainable engineering education and what can be done in the near future.

II. SUSTAINABILITY IN ENGINEERING EDUCATION

Unlike professions such as the medical profession, the engineering profession has a shorter path to the workplace. Engineers are not required to pass a professional licensure exam to be employed, though engineers must be individually licensed before practicing or soliciting business. Typically, to obtain a professional engineering license in the US, the engineer must be a graduate with a bachelor's degree from an ABET-accredited institution demonstrating at least 48 months of education, must have passed the engineering fundamentals (FE) exam, must demonstrate at least 60 months of education and/or experience in order to be eligible to take the Professional Exam (PE) exam, pass the PE exam, and finally demonstrate 96 months of education and/or experience to apply for the license. In view of these requirements, most ABET-accredited programs in the US require a total of 120-128 credits (semester hours) of undergraduate coursework. For example, a 120-credit degree in civil engineering may include 17 hours of mathematics, 8 hours of physics, 4 hours of chemistry, 18 hours of general education, English and economics, 7 hours of basic

[1] The phrase "I know it when I see it" was used in 1964 by US Supreme Court Justice Potter Stewart to define his threshold for obscenity in an infamous case argued before the US Supreme Court.

science and engineering science, and the remaining 66 hours of engineering courses directly related to the profession. This last number as a percentage of the total requirement, has steadily declined over the years much to the consternation of those looking to hire fresh engineering graduates. The situation in India is equally challenging and the new national education policy [Ministry of Human Resource Development, 2020] states unequivocally the challenge – "The global education development agenda reflected in the Goal 4 (SDG4) of the 2030 Agenda for Sustainable Development, adopted by India in 2015 - seeks to "ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" by 2030. Such a lofty goal will require the entire education system to be reconfigured to support and foster learning, so that all of the critical targets and goals (SDGs) of the 2030 Agenda for Sustainable Development can be achieved."

Hence, the fundamental questions confronting educational institutions can then be summarized as follows:

(1) How does one structure an affordable education that is inclusive and equitable? The current wisdom is that this structure requires a 4-year full time education.

(2) What are the key components of a fundamentally strong curriculum to prepare a graduating engineer for the workplace? The example shown earlier contains physical sciences (mathematics, physics, chemistry, basic and engineering science courses), liberal arts, social sciences, and humanities (general education, English and economics courses), and engineering as the three main components. One could argue that these key components cannot be ***taught*** at the workplace making the role of an educational institution unique and essential.

(3) How can the "essentials" that are not directly associated with an engineering discipline be integrated into an existing curriculum? Over the years, the list of essentials has included such areas and topics as computer programming (1980 onwards?), ethics (1990 onwards?), entrepreneurship (2000 onwards?), and now sustainability, thanks to increased awareness of the effects of climate change. Do these areas and topics warrant creation of new courses? What is clear is that with an already full slate of courses, any addition of new courses would imply dropping existing courses.

(4) Can an institution create its own unique brand without compromising rigor, quality, and accessibility while maintaining its accreditation? The accreditation process works quite differently in India (AICTE/NBA) and the US (ABET). Often, engineering colleges in India that are not autonomous, have limited opportunities to critically examine and reform their curricula, leave alone create their own unique brand. Those that are private and autonomous are likely to be risk averse in being too innovative for obvious reasons [Sharma, 2021]. A much larger fundamental question is whether there are enough qualified teachers to teach engineering courses?

(5) Have the accreditation requirements become burdensome and outdated thus stifling the creation of creative curricula? In 2017, Caltech decided that they would no longer pursue ABET accreditation as [Arnaud, 2017] "… the process of engineering accreditation by ABET limits our ability to offer the best possible education to Caltech's remarkable cadre of students." While there is no stampede to move out, a number of programs in US universities have decided on the same course of action.

These fundamental questions do not have ready and easy answers. The focus of this paper is to see how, under these challenging conditions, educational institutions can incorporate the "essential" sustainable engineering into their curriculum. In the next two sections, we will examine the myths associated with sustainability and teaching sustainability, followed by what engineering institutions are and should be doing to integrate sustainability in engineering education. For the sake of the planet, we will assume that climate change and sustainability are intertwined and have a dual relationship.

III. MYTHS

Engineers are problem solvers. Sustainability is a huge part of solving the problems associated with climate change. This implies that engineers setting out to solve this global problem must not only understand the issues and the science, but must be able to differentiate myths and facts. A recent paper [Milovanovic, 2022] found that only 30 percent of US students in their fourth year understood the specific causes and methods associated with climate change science.

MYTH 1: Sustainability is unachievable

This myth exists in spite of the fact that in 1987 the Brundtland commission report [World Commission on Environment and Development, 1987] identified such groundbreaking thoughts as – "The sustainability of ecosystems on which the global economy depends must be guaranteed.", "The challenge of finding sustainable development paths ought to provide the impetus – indeed the imperative – for a renewed search for multilateral solutions and a restructured international economic system of co-operation.", "Many critical survival issues are related to uneven development, poverty, and population growth. They all place unprecedented pressures in the planet's lands, waters, forests, and other natural resources, not least in developing countries", etc. The last quote is ironic since developed nations have contributed as much to current day global warming and sustainability problems as some developing countries are doing today. Like "Nero fiddled while Rome burnt" (he literally really did not, but showed little or no leadership), today's leaders and society have contributed to this myth with a variety of statements – "Good sustainable practices are expensive.", or "Good sustainable practices lead to lower standards of living." I have not provided references here since a quick internet search will show numerous websites (not scientific journal articles) perpetuating these myths without presenting all the facts. Yes, living a life based on sustainability and sustainable science will require sacrifices and sometimes a radical change in thinking, but the alternatives are devastating.

MYTH 2: Sustainability cannot be taught

This myth derives its energy from ignorance starting with what I alluded to in my opening paragraph that since sustainability is difficult to define, no one knows how to teach sustainability. After several decades of study, there is a wealth of scientific knowledge for faculty in engineering institutions to teach sustainable science and engineering. Sustainability just like ethics, or entrepreneurship, or computer programming, cannot and should not be taught as discrete, standalone course(s). This discrete approach would be as foolish as having distinct courses to teach Microsoft Office, or AUTOCAD, in 4-year engineering curricula. It has been my experience that the lessons learnt from the 1980s on teaching computer programming, and from the 1990s on teaching ethics are simply being ignored. Requiring one or two courses in computer programming in the first two years does not show the students the power of writing computer programs until writing computer programs becomes as ubiquitous as using a scientific calculator. Unfortunately, in almost all my conversations with faculty from all over the globe, very few, if any at all, courses in all the four years of undergraduate education require that students write their own programs to solve problems that would otherwise by tedious to solve "by hand". The philosophical discussions on what programming language, or operating system, or canned programs to use, result in no beneficial conclusions; hence, the reinforcement that is needed in courses that follow the basic computer programming courses, simply does not exist. A similar problem exists with teaching ethics. Study after study has shown that teaching ethics and analyzing ethical behavior as case studies, has done little to improve understanding of unethical behavior or what engineers need to do when confronted with ethical dilemmas [Jenkins, 2020; Lawlor, 2021]. Sustainability (much like computer programming) needs to become an integral part of many courses.

A viable solution to this problem is possible only through collective leadership and action. For example, in [Davidson et al., 2016], "Solving societal problems on a global scale and for indefinite time periods requires solutions that are sustainable, and engineers are now recognizing the need to incorporate sustainability into all engineering problem solving. For this reason, engineering programs around the country are developing new courses, creating educational modules as part of existing courses, and conducting research in sustainable engineering education. Unfortunately, these efforts are fractured and disjoint: most universities are working independently to make progress in this area, and there is a great deal of re-inventing similar material and repeated efforts. Unlike core engineering courses, there is no standard body of knowledge for sustainable engineering." I will discuss in some detail (Section IV, Action 3), the issues that administrators in educational institutions as well as teachers and students must become familiar with in order to break this impasse.

MYTH 3: New technologies can solve the problems

Society thrives on looking for a silver bullet. Unfortunately, no silver bullet exists today to solve climate change and sustainability related problems. Technologies that show promise in the smaller setting are difficult to scale to meet world needs. Yet, a recent report [Hellstern et al., 2021] that is more aspirational than reality, states that "The good news: McKinsey research on Europe's net-zero pathway suggests that climate technologies that are already mature could, if deployed widely, deliver about 60 percent of the emissions abatement that will be needed to stabilize the climate by 2050. The challenge is that further abatement must come from climate technologies that aren't quite ready, including 25 to 30 percent from technologies that are demonstrated but not yet mature and another 10 to 15 percent from those still in R&D. …When, for example, will clean hydrogen cost $1 per kilogram: in 2025 or 2050?" As expected, this document reads like an investment guide rather than a document whose analyses are based on sound scientific and engineering principles. Can the world wait another 28 years for a solution to a problem that is acute today?

MYTH 4: Setting a target implies meeting that target

In the hope of finding the silver bullet, i.e., future technologies, countries and industries have set targets decades into the future. For example, the 2015 Paris Agreement [Wikipedia, 2016] set a global goal to reach net zero emissions by 2050. This is purely aspirational that is not backed by neither today's science and technology nor near-term technological breakthroughs. In fact, the outlook based on today's inaction by major countries, is quite pessimistic [Andrew, 2020].

MYTH 5: Only some engineering majors can practice sustainability

This is in fact a reality only because educational institutions have allowed this myth to survive. In [Allen et al., 2009], the 286 academic units that responded to the questionnaire out of 1368 academic units from 364 different US institutions, were grouped into seven categories – (1) Chemical, Bio, and/or Materials (82 departments), (2) Civil, Architectural, and/or Environmental (59 departments), (3) Mechanical, Aero, and/or Manufacturing (52 departments), (4) Electrical and/or Computer (41 departments), (5) Industrial, Systems, and/or Sustainable Engineering (18 departments), (6) General (18 departments), and (7) Other including Petroleum, Mining, and Nuclear (16 departments). The academic units were asked if sustainable engineering was integrated into the curriculum in the form of courses. No definition of sustainable engineering was provided to the participants, although prompts were provided in the form of a list of examples of sustainable engineering tools, concepts, and topics: life cycle analysis, natural resource management, climate change, design for environment, policy and regulations, renewable energy, industrial ecology, economics, green design, material flow analysis, pollution prevention, and reuse and/or recovery of products and materials. The types of sustainable engineering courses offered are summarized in Fig 1. For a variety of reasons, it should be noted that only 57 of the 286 departments (20%) are included in the statistics indicating the difficulty in getting reliable data- "In part, this is likely a reflection of the difficulties of conducting a true census; it may also be indicative of the need to improve coordination and communication between systemic activities at the department level and individuals working to promote sustainable engineering within the department. The third possibility is that although more than 80% of the responding departments report offering sustainable engineering focused material in their curricula and/or courses into which sustainable engineering content has been integrated, 35% of these report offering only integrated courses and no sustainable engineering focused courses (Table 5.1). These departments, therefore, may not have an obvious sustainable engineering champion who would have been contacted through the champion questionnaire."

Table 5.1. Types of Courses Reported

Engineering Discipline	No Sustainable Engineering Focused or Integrated Courses		Sustainable Engineering Focused but No Integrated Courses		Integrated Courses but No Sustainable Engineering Focused		Both Sustainable Engineering Focused and Integrated Courses	
	#	%	#	%	#	%	#	%
Chemical, Bio-, Materials	7	11.0%	3	6.1%	21	40.2%	28	42.7%
Civil, Architectural, Environmental	9	11.9%	5	5.1%	33	35.6%	35	47.5%
Electrical, Computer	16	39.0%	1	2.4%	14	34.1%	10	24.4%
General	1	5.6%	1	5.6%	8	44.4%	8	44.4%
Industrial, Systems, Sustainable	3	16.7%	0	0.0%	6	33.3%	9	50.0%
Mechanical, Aero-, Manufacturing	10	19.2%	4	7.7%	15	28.8%	23	44.2%
Other	4	25.0%	2	12.5%	5	31.3%	5	31.3%
Total	50	17.5%	16	5.6%	102	35.7%	118	41.3%

Fig. 1. Types of courses reported in [Allen et al., 2009]

The engineering discipline where lack of these courses is most prevalent is electrical and/or computer engineering with 73% having no courses. Though the data is dated, anecdotal evidence shows little or no improvement in some departments (since 2009) including electrical/computer engineering. In the context of Indian academia, the major that is missing from the table is computer science. Both the AICTE and NBA websites do not show enrollment by major, but I suspect unofficial numbers to be reasonably accurate – In 2020, there were 935,270 students with computer science and engineering as their major compared to the most popular engineering major, mechanical engineering, that had 684,930 students [Kanwal, 2022]. The final figures are likely even more lopsided given the fact that a large number of students with engineering degrees are employed by computer science and information technology industries in India.

IV. PROACTIVE ACTIONS

Notwithstanding a very pessimistic outlook for the future [Watts, 2020], a positive, optimistic outlook demands that educational institutions be proactive in curing the ills of the current while preparing for the changes in the near future.

ACTION 1: Stop perpetuating myths

If you repeat a message often enough, it becomes the truth. There are two prime examples of leading industry giants telling lies – the "Big Tobacco" [NIH, 2018] and the plastics industry [NPR, 2020]. One of the biggest sustainability-related industries, the building industry, is in danger of doing the same by equating the low-hanging fruit (LEED certification, Green Building label) with what really needs to be done to meet the sustainability challenges.

ACTION 2: Really understand the issues

There is plenty of blame to go around – government and industries kick the can down the road hoping that today's problem can be handled by someone else next decade, and sustainability activists who are more interested in ideology than working with genuinely interested parties to find a real solution in today's world. Growing up in India during the 1960-70s, I learnt to appreciate the bare necessities of life as illustrated by a popular Hindi film *Roti, Kapada aur Makaan* (Fig. 2).

From a knowledge enterprise viewpoint, the urge to find practical solutions should be shared by academia, think tanks, not-for-profit entities, industry R&D divisions, and government research and regulatory agencies. One way of capturing the conundrum is to breakdown the issues into a **Man-Machine-Management** problem as shown in Fig. 3. The **Man** component today is quite different than the depiction in Bollywood movie. Apart from the basics, healthcare and especially, the time components play a much bigger role in human aspirations. No longer does time involve time spent on generating income, but also includes the time that is spent in leisure activities. While much of the world has moved towards meeting the 1948 UN mandate "Everyone has the right to a standard of living adequate for health and well-being for himself and for his family, including food, clothing, housing and medical care and necessary social services." [UN, 1948], leisure activities are no longer the privilege of the rich. For good or bad, the world economy is increasingly human-centric. The US census bureau released a report [US Census Bureau, 2021] that shows how the world has changed just in the last decade: "Among all households in 2018, 92% had at least one type of computer and 85% had a broadband internet subscription. Smartphone ownership surpassed ownership of all other computing devices. Smartphones were present in 84% of households, while 78% of households owned a desktop or laptop. Tablet ownership fell behind at 63%. While many households had home-based internet connections, others relied on a cell phone provider and connected to the internet through a smartphone. Households relying only on a smartphone were more likely to make $25,000 or less, be headed by someone under 35 years old or have a Black or Hispanic householder." How Bill Gates was wrong in his tech forecast [Hanbury, 2019]!

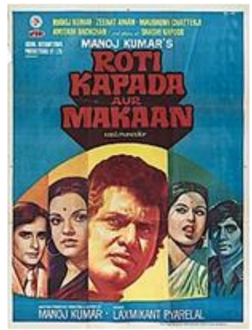

Fig. 2. A popular 1974 Bollywood film

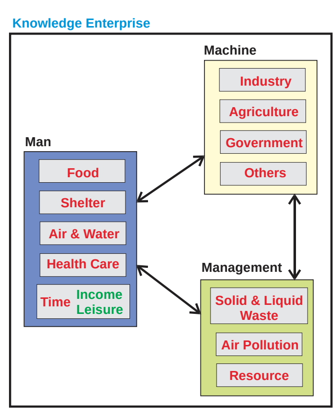

Fig. 3. Man-Machine-Management (MMM) Conundrum

The resources in the **Machine** component are largely spent on meeting human needs. Unsurprisingly, both Man and Machine deplete resources, and generate waste and pollution that then becomes a **Management** problem.

A change in thinking, that is already taking place, is to take a radically new look at how society manages itself. For example, I will talk about three terms that form a love triangle [Nebel, 2020]: Cradle-to-Cradle (C2C), Life Cycle Analysis or Assessment (LCA), and Circular Economy (CE). A life cycle approach looks at a product, process, or service through its entire life. For example, a computer is made of a large number of different minerals that need to be mined, transported, and processed to make computer parts. These parts are then transported to the factories that make larger components and so on till the final computer is made. Each of these steps require depletion of finite resources, are energy intensive, and generate waste and pollutants. Once the computer is put to use, it requires power to operate that is likely coming from non-renewable sources. Finally, what happens to a computer that has reached its end of useful life is of paramount importance – will it be broken down into its components and the components recycled, are the components recyclable, will it be repurposed, or discarded to generate solid waste? In LCA, all stages in the life cycle of the product are examined with particular regard to quantifying environment impact. In a C2C analysis, what happens at the end of the product or system, is also given importance – downcycling is discouraged, upcycling is encouraged [McDonough & Braungart, 2002]. Circular economy is a more recent concept tying production and consumption in the context of three principles - eliminating waste and pollution, circulating products and materials, and the regeneration of nature [Wikipedia, 2022].

We will look at where these three modes of thinking can be used in academia in the next section.

ACTION 3: A Band-Aid solution will not do

The findings of a study conducted back in the early 2000s [Allen et al., 2009] concluded that "To date, there has been a significant level of "grass-roots" activities but little structure or organization. The next step will be for engineering accreditation bodies to think critically about what should or should not be included in a curriculum into which sustainable engineering has been incorporated." My personal experience is that there has been very little fundamental change in the curricula even in the limited areas of study (civil, chemical, mechanical) for which sustainable engineering is perceived to be a natural fit. The "essentials" simply cannot be taught as standalone courses. For example, it is counterproductive to teach one class just on ethics if ethics is not tightly integrated into every course [Rajan, 2017].

An analysis of the man-machine-management conundrum is likely to show that today a vast number of courses can be easily tuned to bring in sustainable engineering into the courses. The main topics include – energy generation and use, selection of materials and chemicals, water treatment and supply, waste management, air pollution, multi-objective optimal design, life cycle analysis, resilient design for climate change, design for sustainability, regulatory requirements, land use and management, and so on.

Using an ABET-accredited civil engineering (CEE) degree program as an example, I will illustrate how an educational institution can work effectively towards making its curricula and its students aware of the MMM Conundrum. The degree program (see Fig. 4) requires 17 credit hours of mathematics and statistics, 8 of physics, 4 of chemistry, 6 hours of social-behavioral science and humanities/arts/design courses, 6 hours of English, 3 hours of economics, 3 hours of engineering science, 7 hours of basic science and engineering science courses, 51 credit hours of required CEE courses, and 15 hours of CEE technical electives.

Term 1	**CHM 114**	**MAT 265**	**FSE 100**	**ASU 101**	**ENG 101**	**HU/SB (C or G)**	Semester
	Chemistry	Calculus I	Intro to Eng	ASU Exp	Composition	Elective	Credit Hours
	4	3	2	1	3	3	16
Term 2	**MAT 242**	**MAT 266**	**PHY 121**	**PHY 122**	**ENG 102**	HU/SB (G or C)	Semester
	Linear Algebra	Calculus II	Physics I	Physics I Lab	Composition	Elective	Credit Hours
	2	3	3	1	3	3	15
Term 3	**MAT 275**	**MAT 267**	**PHY 131**	**PHY 132**	**CEE 210**	**ECN**	Semester
	Mod Diff Q	Calculus III	Physics II	Physics II Lab	Statics	211 or 212	Credit Hours
	3	3	3	1	3	3	16
Term 4	**CEE 212**	**CEE 213**	**IEE 380**	**MAE 241**	Basic Science		Semester
	Dynamics	Deform Solids	Prob/Stats	Thermo	Elective		Credit Hours
	3	3	3	3	3		15
Term 5	**CEE 341**	**CEE 353**	**CEE 384**	**CEE 300**	Engineering		Semester
	Fluid Mech	CE Materials	Num Meth	Eng Bus Pract	Science Elect		Credit Hours
	4	4	3	3	1		15
Term 6	**CEE 321**	**CEE 351**	**CEE 361**	**CEE 372**			Semester
	Structures	Geotech Eng	Environ Eng	Transp Eng			Credit Hours
	4	4	4	3			15
Term 7	**CEE 400**	Technical	Technical	Technical	Technical		Semester
	Earth systems	Elective	Elective	Elective	Elective		Credit Hours
	3	3	3	3	3		15
Term 8	**CEE 486**	Technical	Technical	Gen Ed			Semester
	Integ Design	Elective	Elective	Elective			Credit Hours
	4	3	3	3			13
		Required Courses				**TOTAL**	**120**

Fig. 4. List of courses for an undergraduate degree in civil and sustainable (HU: Humanities, Arts, Design; SB: Social-Behavioral Science; L: Literacy; MA: Mathematics; CS: Computer/Statistics/Quantitative Applications; G: Global Awareness; BS: Basic Science; ES: Engineering Science; TE: Technical Elective)

The additional courses not identified in Fig. 4, that are available for students to use as a part of their degree, are shown in Table 1.

TABLE 1. COURSES AVAILABLE TO THE STUDENTS

Course	Title	Qualifies As
PUP 442	Environmental Planning	TE
SOS 300	Advanced Concepts and Int. Approaches in Sustainability	TE
SOS 494	US Energy: Pathways to Sustainability	TE
MAE 494	Renewable Energy Engineering	TE
MSE 494	Bioinspired Materials and Biomaterials	TE
EGR 476	Energy Infrastructures	TE
PUP 190	Sustainable Cities	SB/HU
CEE 181	Tech., Social, and Sustainable Systems	SB/HU
CEE 401	Sustainable Engineering and Materials	TE
CEE 402	Energy Efficient Buildings and Systems	TE
CEE 412	Pavement Analysis and Design	TE
CEE 420	Steel Structures	TE
CEE 421	Concrete Structures	TE
CEE 440	Hydrology	TE
CEE 441	Water Resources Engineering	TE
CEE 466	Urban Water System Design	TE
CEE 481	Civil Engineering project Management	TE
CEE 485	Sustainable Civil & Environmental Systems Engineering	TE

The links between sustainable topics and the courses in the degree program are shown in Table 2. The links are strong for some topics, while for others, tenuous or non-existent.

TABLE 2. SUSTAINABLE ENGINEERING TOPIC-COURSE LINK

Sustainable Engineering Topic	Course(s)
energy generation and use	MAE 494, EGR 476, SOS 494
selection of materials and chemicals	CEE 353, CEE 401, CEE 421, CEE 420, CEE 421, MSE 494
water treatment and supply	CEE 440, CEE 441
waste management	CEE 361
air pollution	CEE 361
multi-objective design	CEE 486
life cycle analysis	CEE 300
resilient design for climate change	Not covered
design for sustainability	CEE 321, CEE 485, CEE 486
regulatory requirements	CEE 181, PUP 190, SOS 300
land use and management	PUP 442, CEE 400

Similar examples can be created for other degree programs where the topic-courses nexus may not be that evident. For example, in a recent paper [Gomes et al. 2019], a strong pitch is made for "the new field of computational sustainability" by using concepts associated with uncertainty, machine learning, optimization, remote sensing, and decision making. However, I did not find sustainable engineering courses had become part of the computer science curriculum. Where computer science and engineering, and electrical engineering can draw their inspiration from is from the National Academy of Engineering (NAE) Grand Challenges for Engineering [NAE, 2008]. Fourteen challenges encompassing sustainability, health, security, and joy of living make the challenges. One can easily draw the link between electrical engineering and sustainable engineering from the challenges – make solar energy economical, provide energy from fusion, restore and improve urban infrastructure, and advance health informatics.

Finally, there are two actions that I believe, can contribute positively to understanding the nuances of sustainable engineering and take positive action.

ACTION 4: Sustainability begins at home

One leads by example and there is no better way of understanding sustainability than to start practicing it in every facet of one's life. For Indian institutions that lack resources (large college or university with engineering, physical sciences, social sciences, and other non-engineering departments) to get help in incorporating sustainability ideas in their courses, one can start with very simple exercises in the 1st and 2nd year courses. As a part of IUCEE's [IUCEE, 2022] educational initiatives, four sustainable engineering domain experts offered an exploratory course to about 300 students from various colleges in India. After my introductory webinars [Rajan, 2022], I posed very simple questions to students with very diverse engineering backgrounds, that would require basic knowledge of physics, chemistry, mathematics, and the ability to search for data. Here is a list of some of those questions.

Q1: Where does water to your house come from? What is the daily consumption per person in your household? Of all the residents in your city?
Q2: How is the liquid waste in your house treated and disposed of?
Q3: How is the solid waste in your house collected, treated, and disposed of?
Q4: Where does electricity to your house come from? How much of power is consumed in your house?
Q5: List all the specific ways you can reduce (a) the water consumption, (b) solid waste, and (c) electricity consumption in your home. What is your estimate of the savings?
Q6: How has climate change effected the city/town you live in? What steps are being taken (or, should be taken) to mitigate the effects of climate change?
Q7: Collect data on the embodied energy (EE) and embodied carbon for a variety of building materials using values applicable for Indian conditions. Cite the source and the reliability of the data.
Q8: Develop a computer program or website to compute embodied energy and/or embodied carbon for building materials. Provide details of the developed computer program. Show examples of how the user interface is used. List what enhancements can be made to make the program more versatile.

Following Q7 and Q8 that were presented after introducing the concept of embodied energy and how energy calculations take place, a more challenging question (Q9) was posed that required more in-depth thinking and some detailed calculations.

Fig. 5. Kulwinder Kaur attends to vegetable plants at her terrace garden in Amritsar [Gill, 2020]

Q9. A rooftop vegetable growing raised bed (2 m x 2 m x 1 m tall), is made of bricks, mortar, and soil (Fig. 5). Compute the embodied energy required to make the structure.

A follow-up question was given the second week.
Q10. Redo the calculations for EE Example - state clearly the assumptions, show all the calculations, and estimate the life cycle of the structure. Propose an alternate material to use for the raised bed and redo the same calculations. Will your alternate design work?

ACTION 5: Reverse rural-to-urban migration

Happiness is not hidden in cities waiting to be discovered. And yet, the rural-to-urban migration is taking place at an alarming rate. Most cities with large populations (greater than a few million) are congested and polluted with unhealthy environment attracting rural populations like a magnet. Of the top 10 most populated cities in the world, 7 are in Asia (Tokyo, Delhi, Shanghai, Dhaka, Mumbai, Beijing, Osaka), 1 in South America (Sao Paulo), 1 in North America (Mexico City) and 1 in Africa (Cairo). Compared to China and Japan, the rural population in India is still relatively large – "65% of the people of India lives in rural areas and 35% live in urban areas. The proportion residing in urban areas has doubled in 2020 from 17% in 1950 and is expected that half of the India population will be in urban areas by 2050." [UN, 2018]. The reasons for migration are many – lack of employment, medical, and educational opportunities, famine, climate change, war, etc. Educational institutions especially engineering can find solutions to eliminate these reasons.

V. CONCLUDING REMARKS

Sustainable engineering concepts are making inroads into engineering curricula driven by the increased awareness of what climate change and unsustainable practices are doing to our world. Fortunately, the science and engineering to handle the global problems are mature and continuously evolving. However, there seems to be an unwillingness in the political world to make the required changes. When asked about extreme effects of climate change, NAE President [Frueh, 2021] stated that "Even if we put no more CO_2 in the atmosphere now, we are still going to have problems. Human beings have been adapting over millennia, and we can do it better than our ancestors. I think the real issue is political will. There are engineering changes that can be made — for example, building houses that are more resilient to wind and rain — but the issue is political will."

My personal assessment is that the time for talk is over. With a huge dose of luck, small, nimble nations and communities will learn to adapt, survive, and perhaps, thrive. In larger nations, the disparity between the haves and have-nots will increase. There is hope if the entire world works collectively towards solving climate change and sustainability problems. It is time for engineers and scientists to become political leaders with the power to make changes. Time is running out.

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