

## Article

# Incorporation of Sustainability Concepts into the Engineering Core Program by Adopting a Micro Curriculum Approach: A Case Study in Saudi Arabia

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**Abstract:** Higher education institutions are increasingly pursuing sustainable development goals in engineering and technology education. The concepts related to operations, production, and consumption continue to gain importance and significance for engineering students. In the engineering profession, the incorporation of sustainability means integrating environmental, economic, and social factors into the evaluation of design processes, products, and services. Therefore, it is necessary to develop an engineering program that along with the technical content, also fosters a critical sense regarding the social and environmental aspects of the field. The current status of sustainability education in engineering programs offered in Saudi universities is not very promising. In this paper, we explore the use of existing university curricula to incorporate sustainability elements into engineering education and training. Sustainability concepts were introduced into selected courses by using a micro-curriculum approach. Moreover, a standalone course is also introduced. We observed that this approach has been successful in integrating sustainability into the engineering curriculum. We recommend that such an approach be used to develop sustainability awareness in engineering programs.

**Keywords:** sustainability; education; engineering; micro-curriculum; PMU

## 1. Introduction

Humans control the earth's resources and use them for fulfilling their needs. These resources, however, are limited in capacity and are consumed in increasingly massive quantities as a result of globalization and expanding economic development within the span of recent decades. At present, the problem to be addressed is the lack of regenerative capabilities to satisfy needs and ease the burden that is being put on the planet by industrialized civilization. If no solution is found, these limited resources will diminish, with catastrophic results for the global ecosystem.

An effective solution is to incorporate processes with sustainability so that current needs are secured without compromising future generations. This can be achieved only by incorporating sustainability's three essential pillars: environmental protection, social development, and economic growth. The idea of sustainability assumes that nature and the environment are not inexhaustible resources and therefore, must be rationally used and protected. Sustainability promotes social development by seeking coherence between cultures and communities to achieve satisfactory levels of quality of life, health, and education. Moreover, sustainability seeks equal economic growth that maintains wealth for all without harming the environment. Implementing the ideas of sustainability,

however, requires consideration of numerous objectives such as poverty, environmental degradation, climate, inequality, etc., thereby making its widespread adoption challenging [1,2].

Of course anyone who glances at the news is aware of this, but it is necessary to rehearse the consequences of the discrete, rather than integrative analysis of sustainability, because there is evidence that engineering programs, and indeed other programs in the STEM set of disciplines, have a limited experience of incorporating sustainability into their curricula [3]. At the international level, the concept of sustainability was first introduced in the higher education system by the UNESCO-UNEP (United Nations Educational, Scientific and Cultural Organization—United Nations Environment Program) International Environmental Education Program [4]. A number of international and national declarations about the integration of sustainability issues in higher education (HE) institutions have been developed in subsequent years [5]. In Europe, the early initiative was the Co-operation Program in Europe for Research on Nature and Industry through Coordinated University Studies (COPERNICUS), which was established by Conference of the Rectors of Europe (CRE) to collaborate on common environmental issues. In this context, CRE developed the COPERNICUS charter for Sustainable Development in 1994. On the Global scale, another important declaration is the Ubuntu Declaration on Education, Science and Technology for Sustainable Development in 2002. This declaration was signed by major academic institutions worldwide like the Third World Academy of Sciences (TWAS), United Nations University (UNU), the International Association of Universities, and the Science Council of Asia, amongst many others [6].

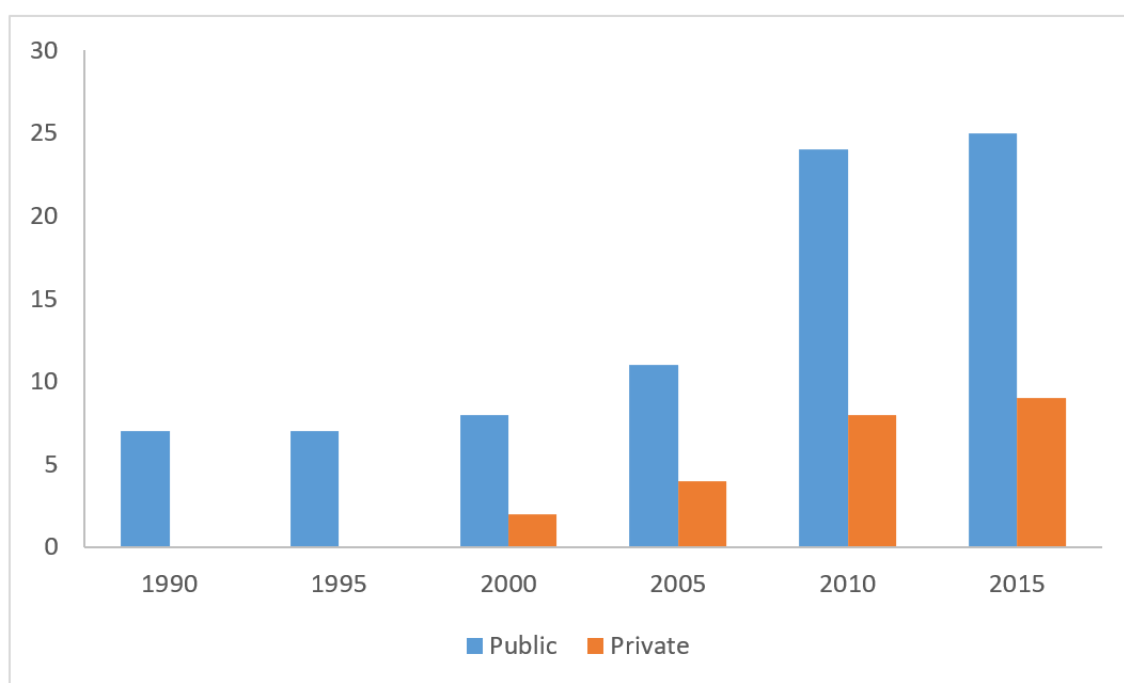
In the engineering profession, the incorporation of sustainability means integrating environmental, economic, and social factors into the evaluation of designs of processes, products and services. Generally, the ‘processes’ consists of all kinds of activities by which the human civilization advances itself. These include tasks that start from extracting resources and transforming them into consumer products. Considering energy resources, fossil fuels must be transported and then processed to generate electric power, heat and light. All substantial human activity makes use of these resources, which are thus eligible for consideration in light of sustainability. Engineers are responsible for organizing and optimizing these processes by visualizing all aspects of the system and their collective interplay. Their tasks include designing supply chains to deliver components to manufacturers within deadlines, determining the optimal combination of raw materials to formulate finalized products, etc. [7,8]. The endeavors of United Nations in adopting sustainable development goals (SDGs) for the 21st century have triggered incorporation of sustainability concepts in the curricula of primary to higher education. UN-SDGs are focused on the environment (climate change, life on land, life below water), social (gender equality, peace) and economic (no poverty, decent work, and economic growth) domains of sustainability. In addition to that, SDGs go beyond three basic spheres of sustainability by emphasizing quality education (#4) and partnerships for the goals (#17). The National Academy of Engineering (NAE) have defined 14 grand challenges for engineering based on cross-cutting themes, which include sustainability [9].

Given these job descriptions, future engineers are eligible to address the need for incorporating sustainability in systems and overcoming the challenges that come as a part of its implementation. Industrial engineers can examine the requirements of a system and alter different parts with the motivation to achieving the system’s ultimate goal while including sustainability. For example, they could consider minimizing resource consumption to foster environmental protection. Furthermore, engineers are trained with the characteristic of working towards maximum economic gain. While achieving this goal, the tools of the field can also be used to reach additional goals which were unlikely to be considered in the past. These additional goals such as minimizing resource consumption or maximizing population health can be combined with the objective of achieving profits to attain an overall balanced system, which achieves both its sustainability and economic goals [10,11].

The best way to accomplish this transformation in the mindset, and to prepare engineers to implement sustainability in their careers, is through their education. Modern higher education institutions are increasingly striving to educate the future professionals who are market ready. Mere

technical training is no longer enough to meet the needs of the society. Therefore, it is necessary to develop engineers who along with technical knowledge, also have a critical sense regarding the social and environmental aspects of their profession [12,13]. Accordingly, sustainability needs to be central to the design of curricula in higher education. Many international declarations are regarded as landmarks for including sustainability into higher education, especially EESD (Engineering Education for Sustainable Development) and the Barcelona Declaration. Recognizing the variety of possible applied situations, the apprehension about incorporating sustainability into engineering courses has become an even more serious concern for curriculum development [13].

In the recent decades, the exponential growth of universities in the Kingdom of Saudi Arabia [14] has clearly indicated its intentions towards sustainable national development and qualified human resources across all provinces of the Kingdom (Figure 1). In a recent study, it was revealed that academic courses relevant to sustainability are lacking in Saudi Arabia [15]. Most Saudi universities need to integrate sustainability concepts in the curriculum and promote research and scholarship in this direction.



**Figure 1.** Growth of public and private universities in Saudi Arabia.

There are various ways to introduce sustainability concepts and disseminate information on how to achieve it through engineering practice; it is especially advisable to take these steps early in an engineer's education [16]. This gives time for these concepts to take root and be fully absorbed into the budding engineer's professional consciousness. Through a pilot program at Prince Mohammad Bin Fahd University in the Eastern Province of the Kingdom of Saudi Arabia, we endeavored to achieve this objective of introducing sustainability concepts into the engineering curriculum through the implementation of sustainability elements into the core curriculum. This paper presents our findings and conceptualizes them to suggest a process by which sustainability concepts can be efficiently incorporated into an engineering curriculum.

## 2. Methodology

To initiate the process of introducing sustainability concepts into the University Core Program, we first defined the objectives we sought to achieve through the enhanced curriculum. We aimed to offer engineering students multiple experiences that would demonstrate what it means to have a

sustainable attitude and to enable the development of both the desire for and the skills to use with engineering approaches to sustainable practices.

The broad goals of the project were defined as follows:

1. Enhance the student's understanding of concepts in sustainability.
2. Imbue selected core and engineering courses with new advanced material addressing sustainability concerns that relate to the theme of each revised course.
3. Advance students understanding of the influence of engineering practices on the environment and humanity.
4. Increase students' skills to integrate engineering tools and methods with sustainable practices.

We then framed the scope of our work by defining the specific learning outcomes that we aimed to achieve through curricular enhancements. The course learning outcomes (CLOs), we defined could be measured through both qualitative evaluations and quantitative assessments. Students should be able to:

1. Define and understand the concept of sustainability.
2. Identify the key characteristics of human and natural systems as they pertain to sustainability.
3. Analyze sustainability from a multidisciplinary perspective and understand the main doctrines of diversity.
4. Elaborate the role of sustainability aspects in an organization.
5. Explain sustainability theories and applications in a business context.
6. Learn how to make decisions to maintain and run eco-friendly industry.

To select the courses most suitable for the incorporation of sustainability elements, we first sorted the courses offered by engineering departments at our university, into two groups: those that teach strategies and critical thinking in problem solving, e.g., "Manufacturing Methods & Designs", and those that introduce new perceptions along with the suitable approaches, e.g., "Engineering Economy." A senior design project is a problem-based learning opportunity for the students that helps them to understand sustainability issues in relation to the engineering industry. The main emphasis is on cleaner production and appropriate solutions from knowledge gained from taught courses.

In addition to this process, we developed a stand-alone course entitled 'Introduction to Sustainability' (SUST 1311). This course has been offered to all students in the university's Core Curriculum since 2017. The course description from the Prince Mohammad University (PMU) catalogue is as follows:

"This course familiarizes students to the theory, principles, and practices of sustainability. It will include discussions on sustaining ecological and environmental wellbeing, creating economic prosperity, and safeguarding social justice."

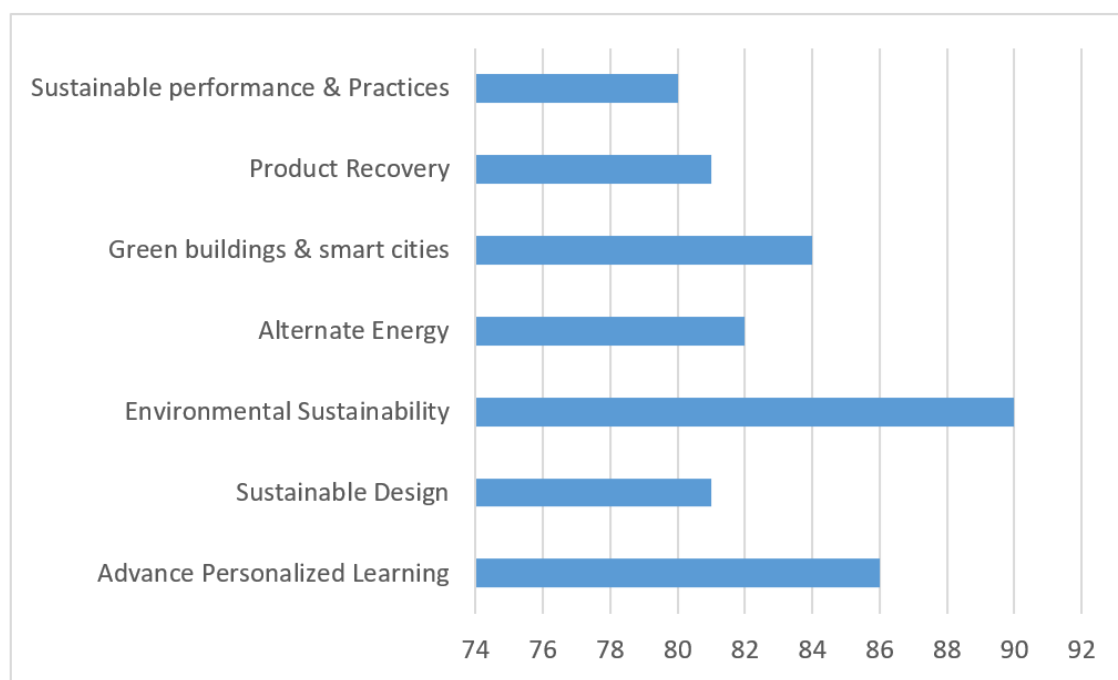
The main focus of this course is sustainable development. Our ultimate goal was the successful implementation of both approaches—inclusion of sustainability concepts into the core engineering program and the introduction of stand-alone sustainability courses in degree programs.

We also identified a list of sustainability notions, we targeted to address through a micro-curriculum. These areas were mapped with United Nations Sustainable Development Goals (UNSDGs) [17,18], as shown in Table 1.

**Table 1.** Sustainability concepts mapped with United Nations Sustainable Development Goals.

	Sustainability Concepts	UNSDG
1	Advance Personalized Learning	SDG#4 Quality Education
2	Sustainable Design	SDG#8 Decent Work & Economic Growth
3	Environmental Sustainability	SDG#6 Clean Water & Sanitation SDG#13 Climate Action SDG#14 Life below water SDG#15 Life on Land
4	Alternate Energy	SDG#7 Affordable and clean energy.
5	Green buildings and smart cities	SDG#11 Sustainable cities & communities
6	Product Recovery	SDG#12 Responsible consumption and production
7	Sustainable performance and Practices	SDG#9 Industry, Innovation & Infrastructure

These concepts were assessed by using specifically designed rubrics with a Key Performance Indicator (KPI) set at 80% (Figure 2).

**Figure 2.** Assessment of targeted sustainability concepts.

Students who enroll in university studies often have little experience with inquiry, research, or scholarly discourse. They expect instead that they can satisfy academic requirements simply by restating content provided by their teachers. Thus, many students are poorly prepared to assume the responsibilities associated with university-level scholarship. The University Core Curriculum Program at PMU consists of additional courses required of all University students. These consist of communication courses in designated competencies as well as the sciences and Mathematics. Critical thinking experiences in the Core Curriculum stress reasoning as a means of discovery and a tool for increasing understanding in both university courses and the student's personal life. Throughout the Core Curriculum, all assignments involve a set of learning outcomes, and expectations are articulated by examples and models. We examined each course in the Core Program in detail to determine the most suitable curriculum adjustments to make. Table 2 presents the mapping of different concepts within the core courses. For competency courses, specific assignments are designed to incorporate

the sustainability concepts. For example, a short synopsis on water conservation, landscaping in the desert, harvesting solar and wind energy, oil related pollution problems, dynamics of the Arabian Gulf, etc. are introduced to the students to complement the defined learning outcomes. In leadership (UNIV1213) and critical thinking (UNIV1212) courses, UNSD goals and policies are introduced to the students in oral presentations. For the engineering curriculum, we considered synergies between existing course content and relevant sustainability content (for example, introducing the design of green buildings and sustainable transportation), and focused on the new ideas. This process allowed us to build tangible links between courses available and content suitable for incorporation into them. Some other examples include CVEN3331 and GEEN4311 which introduce students to the fundamental principles of environmental conservation and ethics that lead to sustainability for humans and the ecological systems in the Arabian Gulf.

**Table 2.** Micro-curriculum concepts incorporated into the Core Courses.

<div> <div>Elements of Sustainability</div> <div>Courses</div> </div>	Define and Understand the Concept of Sustainability	Identify the Key Characteristics of Human and Natural Systems as They Pertain to Sustainability	Analyze Sustainability from a Multidisciplinary Perspective and Understand the Main Doctrines of Diversity	Role of Sustainability Aspects in an Organization	Explain Sustainability Theories and Applications in a Business Context	Learn How to Make Decisions to Maintain and Run an Eco-Friendly Industry
Writing and Research (COMM1312)	-	✓	✓	-	-	-
Technical and Professional Communication (COMM2312)	✓	-	-	-	✓	-
World Regional Geography (GEG1311)	✓	✓	✓	-	-	-
World Civilizations(HIST1311)	-	✓	-	-	-	-
Professional Development and Competencies (UNIV1212)	-	✓	-	✓	-	✓
Critical Thinking and Problem Solving (UNIV1212)	✓	✓	✓	✓	✓	✓
Leadership and Teamwork (UNIV1313)	✓	-	-	✓	✓	✓
Chemistry for Engineers I (CHEM1421)	✓	✓	✓	-	-	-
Environmental Engineering Fundamentals (CVEN3331)	✓	✓	-	-	-	-
Engineering Ethics and Professionalism (GEIT2291)	✓	✓	-	-	-	-
Engineering Economy (GEEN4311)	✓	-	✓	-	-	-
Manufacturing Methods and Design (MEEN3311)	✓	-	-	-	-	-
Sustainable Design (CVEN3344)	-	✓	-	✓	✓	✓
Building Codes and Universal design (COMM1312)	✓	✓	✓	✓	-	✓
Materials Science (COMM1312)	-	✓	✓	-	-	✓

### Assessment Strategies

Assessment strategies included both qualitative and quantitative methods. To test the effectiveness of our approach, we used several methods. We assessed students at the end of the course with quizzes on the material familiarized. In the stand-alone SUST 1311 course, with 156 students, we incorporated assessment strategies such as field reports, volunteering, outreach, and a final written exam. Almost all students scored 80% or higher, on the completion of the course. Although these results are limited by the small sample sizes, they clearly demonstrate that students exposed to the components did absorb a significant amount of their content.

Given that our primary objective was to introduce concepts of sustainability to engineering students, the qualitative assessments give a better picture. To carry out this assessment, the students were given end-of-course surveys at the end of the semester. The following are representative responses:

- The College should offer this course as a certificate, so that I could put it on my CV.
- It is an interesting elective; all engineers should take it.

Most promisingly, students seemed excited about the possibilities that SUST 1311 would enable them to make an impact on society with respect to sustainability. Their responses demonstrate their mindfulness to carry out work in a sustainable manner, and to use their education to achieve the objectives of a sustainable and protected future. One student wrote:

*By taking this course, I realized that I can make a difference by saving the environment. As an engineer, I can think of reducing the use of fossil fuels and prepare for a non-oil based economy in Saudi Arabia. I am using social media to educate my friends and relatives about the importance of a sustainable economy.*

These and many other responses suggest that, if properly applied, the incorporation of sustainability concepts into the study plans can make a big difference in affecting students' perceptions—and, ultimately, in their skills and willingness to apply the concepts in their professional lives.

Other qualitative assessments were made by conducting student's feedback surveys, peer reviews, preceptor views for senior design projects, and employers' surveys. Students were given the opportunity to rate the performance of other senior design projects in terms of sustainability elements. Also, for the senior design, projects evaluators included both academic supervisors and practicing engineers working in industry. The comments by the evaluators were employed to incorporate sustainability concepts in the project. In some cases, a seminar on sustainability was included in the assessment to gauge the student's learning. Employer surveys served as a good opportunity to judge our students' edge over other university graduates in the market. A survey has been completed by a total of 16 employers in 2019. The results showed that our graduates were superior in three domains: sustainability awareness, critical thinking, and innovation.

Quantitative assessment, written quizzes on the materials introduced, and a writing assignment were also used. For example, students are required to write a three page paper on engineering practices to combat climate change in GCC countries. Students were also provided with a relevant rubric to grade the assignment. Although the results are limited by sample size, they clearly demonstrate that students exposed to teaching materials, did absorb the significant quantity of the concept. Environmental Sustainability was the best learned topic, followed by personalized learning. Students showed great interest in environmental issues related to impact oil production and tanker traffic in the Gulf and suggested interesting mitigation measures.

## 3. Discussion

### 3.1. Challenges in Implementation

The major hurdle in injecting the micro-curricula in the existing program structure comes from the diverse nature of sustainability issues. The work load, in terms of student's credit hours, is already heavy



and it is a challenge to incorporate additional volume of sustainability related materials. The addition of sustainability topics might result in loss of other essential materials from the course. In our university, a student centered model is adopted whereby focus is on problem solving, decision making, working in multidisciplinary groups, technical and professional presentation skills, and broader exposure to different topics throughout the program. Therefore, it is possible to integrate sustainability concepts in different courses of the program. The development of micro-curricula was made in such a manner that sustainability concepts were introduced in a basic manner and students are made aware of the significance of environmental importance in any design development. In senior design projects, innovative solutions that require less expenditure of natural resources and work with natural environment are encouraged.

### *3.2. Stand-Alone Courses*

Stand-alone courses (SUST 1311) also played a pivotal role in achieving the objectives. With such courses offered, students have opportunity to learn sustainability at different extents of instructional intensity. It is also noted that such courses should be offered at the junior/senior levels of the educational path. This will help the students to complement the early learned facts with sustainability concepts. Most importantly, these elective courses should help students address the intersection of sustainability with engineering concepts.

### *3.3. Sustainability Co-Curricular Activities*

As an additional step, engineering departments can choose to expand their focus on sustainability through engagement with industry and research activities. Sustainability education could be more effective through capstone courses, undergraduate research programs, design projects and strong support by university management. Extra-curricular activities like posters, essay competitions, speeches, etc. can also augment this education. Organizations like Association for the Advancement of Sustainability in Higher Education (AASHE) support and publish such activities and initiatives.

### *3.4. Gradual Process*

The process of developing and integrating sustainability micro-curriculum in all engineering majors cannot occur in one go. If such changes are too fast and massive, they might disrupt program objectives. We believe in a step-wise approach like starting with a micro-curriculum, then a stand-alone course followed by a full fledge sustainable engineering program.

### *3.5. Consistent Focus*

In order to make sustainability education meaningful and effective, the effort must remain steady and focused. This focus is achieved by establishing a Sustainable Campus office at our university headed by a senior administrator. This office supports activities and initiatives related to sustainable education on campus. For example, in our university the theme of the year for 2018 was Sustainability with a slogan “together towards a sustainable campus”.

### *3.6. Comparison with Other Approaches*

We also consulted relevant recent research in other parts of the world for modifying existing engineering curricula. Galamboski and Ozelkan [7] have published an overview of curricula modification in both engineering and management study plans. Nazzal et al. [11] have used a modular approach to introduce sustainability concepts in industrial engineering curricula in the University of Central Florida. Wilson D. [12] have explored in detail the link between sustainability and engineering education. Murphy et al. [19] have published an overview on how much sustainability content is present in different programs of the university versus traditional content. Allenby et al. [20] have reported an overview of the topic, with emphasis on added content, funding, and relevant

educational techniques. They also talk about usual controversy between sustainability as a fuzzy subject and engineering an abstract science. Pierre et al. [21] used an alternative approach of using modules as stand-alone curricula for short courses. This is in agreement with our approach of introducing micro-curriculum. We also conducted a review of numerous papers discussing sustainability contents in different engineering disciplines. More generally, authors from world over suggest that there is increasing need for this integration across the engineering disciplines [22–26].

#### 4. Recommendations & Conclusions

To assimilate sustainability elements into the curriculum, existing course syllabi must first be surveyed to identify the best candidates to afford the incorporation of diverse sustainability concepts. At this stage, the faculty member leading the initiative must be actively involved with instructors to further modify classroom and lab situations in which sustainability ideas can be most efficiently introduced.

Stand-alone courses focused on sustainability as the core subject are most effective ones. By offering such courses, students have the choice and opportunity to access sustainability directly. This achieves the objective of making sustainability an integrated element of their education. The departments can also choose to focus on sustainability through research and increased interaction between industry and university.

These suggestions, based upon our findings, are meant to serve as a basic outline for the progress of sustainability micro-curricula in connection with existing education programs. Although our work is narrow in scope, our accomplishment in meeting our goals and the encouraging responses we received from learners is quite encouraging, and demonstrates that our approach is effective and applicable.

**Author Contributions:** M.W.A. was responsible for collecting necessary data, evaluation of different core courses and development of learning outcomes. He led the development of stand-alone course materials and syllabus (SUST 1311). F.A. was responsible for literature survey, qualitative assessments and drawing conclusions from surveys. He was responsible for implementation of new stand-alone course in colleges degree plans. All authors have read and agreed to the published version of the manuscript.

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