AC 2012-4565: CHALLENGES FOR INTEGRATION OF SUSTAINABILITY INTO ENGINEERING EDUCATION

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Challenges for Integration of Sustainability into Engineering Education

Abstract

Due to the relative novelty of the subject of sustainability in the engineering community and its complexity, many challenges remain to successful integration of sustainability education in engineering. It is critical to realize such challenges and identify the appropriate strategies so that teaching of sustainability to future engineers can be effective. This paper summarizes the challenges identified from three workshops on "Integrating Sustainability into Engineering: Design Principles and Tools to Expand your Educative Capacity" held in 2010 and 2011, and attempts to propose effective strategies for such integration.

The paper begins with a brief overview of the status of sustainability education in engineering education and then introduces the format of the workshop, the characteristics of workshop attendees, and the major categories and challenges identified during workshops. The major categories include 1) shifting paradigms around sustainability; 2) rigidity of existing education system; 3) lack of new methods of teaching; and 4) lack of resources to teach sustainability. The interrelationship among the challenges within the categories is explored through the use of a causal loop diagram. The paper discusses feedback loops in such a system diagram, the potential leverage points, and effective strategies to address some of the identified challenges for integration of sustainability into engineering education.

Introduction

Interest in integration of sustainability into engineering education has steadily advanced in the last decade. This trend has been observed in the rising number of courses relating to sustainability taught at the university level, funding for related research, the number of publications on the subject, and faculty hires in this area. In a survey conducted several years ago[1-2], it was found that of 270 university faculty respondents, 80% were teaching courses related to sustainability. Among the courses being taught in sustainable engineering, approximately 50% focus on evaluation tools such as Life Cycle Assessment. About 25% integrate sustainability concepts into traditional engineering courses in order to broaden the students' skill set and awareness. Only 15% are cross-disciplinary courses taught in conjunction with other departments that address economic, political, and social aspects of sustainable engineering. It was also reported that 70% of survey respondents have some research activity related to sustainability in engineering. Additionally, about a quarter of a billion dollars was identified in funding for sustainability-related projects in the United States with the National Science Foundation (NSF) being the major granting institution[1]. The increasing sustainability trend is also reflected in the increase in papers presented at the American Society for Engineering Education (ASEE) related to sustainability education[3]. The need for sustainability education drives the strategic faculty cluster hiring in the area of sustainability science and engineering as advertised in the Chronicle of Higher Education. The importance of sustainability in education has been recognized by policy makers worldwide and the period between 2005 and 2014 has been declared the United Nations Decade of Education for Sustainable Development by UNESCO.

Although sustainability education has advanced greatly, many challenges remain to successful integration of sustainability education in engineering due to the relative novelty of the subject of sustainability in the engineering community and its complexity. It is critical to realize such challenges and identify the appropriate strategies so that teaching of sustainability to future engineers can be effective. Several studies discussed the challenges for sustainability education such as financial constraints, curricular barriers, and the lack of clear governmental agenda to guide engineering education as it relates to sustainability, and proposed either theoretical or applied strategies to overcome these challenges[4-7]. However, no study has been found to examine those challenges from a system perspective.

This paper summarizes the challenges identified during workshops on "Integrating Sustainability into Engineering: Design Principles and Tools to Expand your Educative Capacity" held in 2010 and 2011, and explores the interrelationship among the challenges through the use of a causal loop diagram in an attempt to propose effective strategies for the integration of sustainability into engineering education.

Overview of Workshops

The workshops were designed to better understand the challenges faced by faculty in integrating sustainability into engineering curricula while building their capacity to do so through the use of the learning materials we developed. The first workshop of this kind was held at the American Society for Engineering Education (ASEE) Annual Conference (Louisville, KY; June 20, 2010) and the second was at the annual meeting for Society for Advancement of Chicanos and Native Americans in Science (SACNAS) on October 2, 2010. The storyboard of the 3-hour workshop is shown in Figure 1.

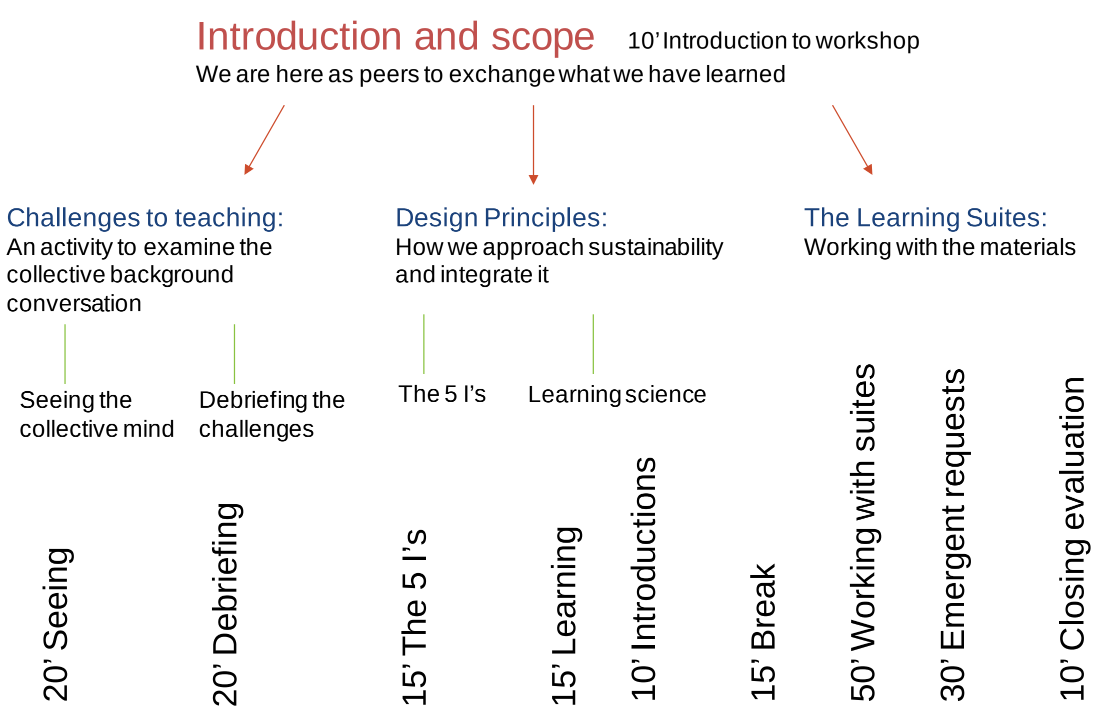

Figure 1. The workshop storyboard. The numbers at the bottom are allocations of time.

During these workshops, participants were first asked to self-identify their level of proficiency in teaching and in sustainability and then to identify challenges they face in incorporating sustainability into engineering education. Those challenges were later organized into major categories collectively by the workshop attendees. After the workshop, a “mind map” was constructed to show the identified challenges in relation to the major categories.

Sixteen individuals registered for the first workshop and 4 of them were faculty from universities serving underrepresented groups. The second workshop was attended by primarily early-career scholars (12 total participants). Of the 12 participants, 7 were female, 6 were under-represented minorities, 2 were from community colleges, and 6 were from Hispanic-serving institutions.

Challenges identified in the workshops

In the first workshop, over half of the group considered themselves in the “expert” category of teaching, a third in the “novice” category and the remaining in the intermediate category. In terms of sustainability, however, the group skewed themselves toward the novice category. The self identification of the second workshop participants is shown in Figure 2. Some identified themselves as more advanced as teachers but all of them self-identified as novices in the area of sustainable design in the second workshop. Some were so novice to sustainable design that they did not even place themselves on the map.

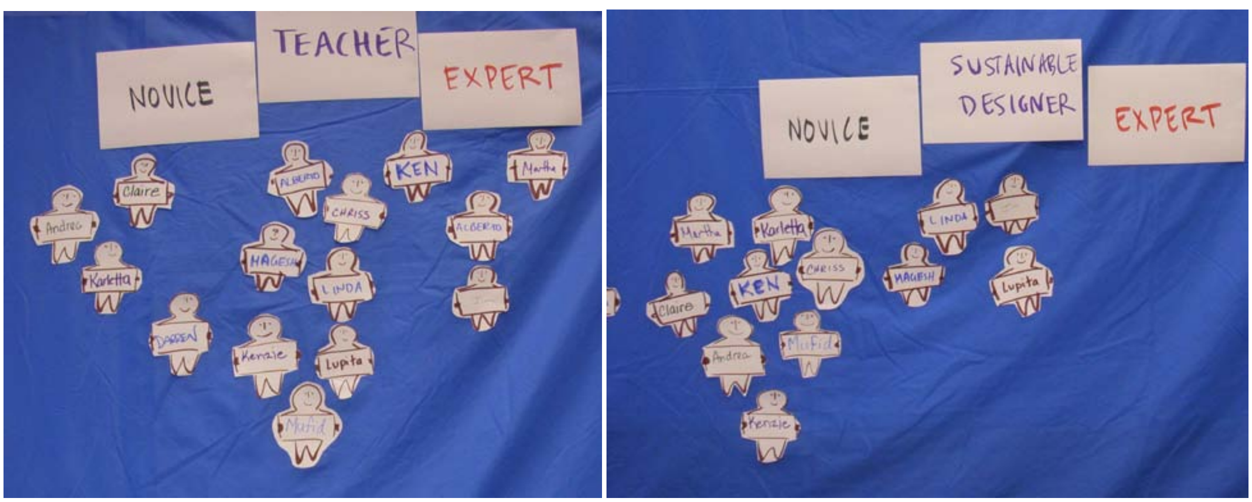

Figure 2. Self identification of the second workshop participants in terms of teaching and sustainable design.

The identified challenges were organized by the workshop participants and Figure 3 represents a compilation of responses from two workshops. Faculty identified four major areas where barriers to integrating sustainability concepts exist: (1) shifting paradigms around sustainability; (2) the rigidity of the existing curricular structure; (3) requirement of new teaching methods; and (4) insufficient resources. The workshop participants agreed that the barriers that pose the greatest difficulty (i.e., are the least “easy” to “fix”) are not technological but those involving the human system, such as “accepting sustainability as engineering,” or “new thinking and new collaborations.”

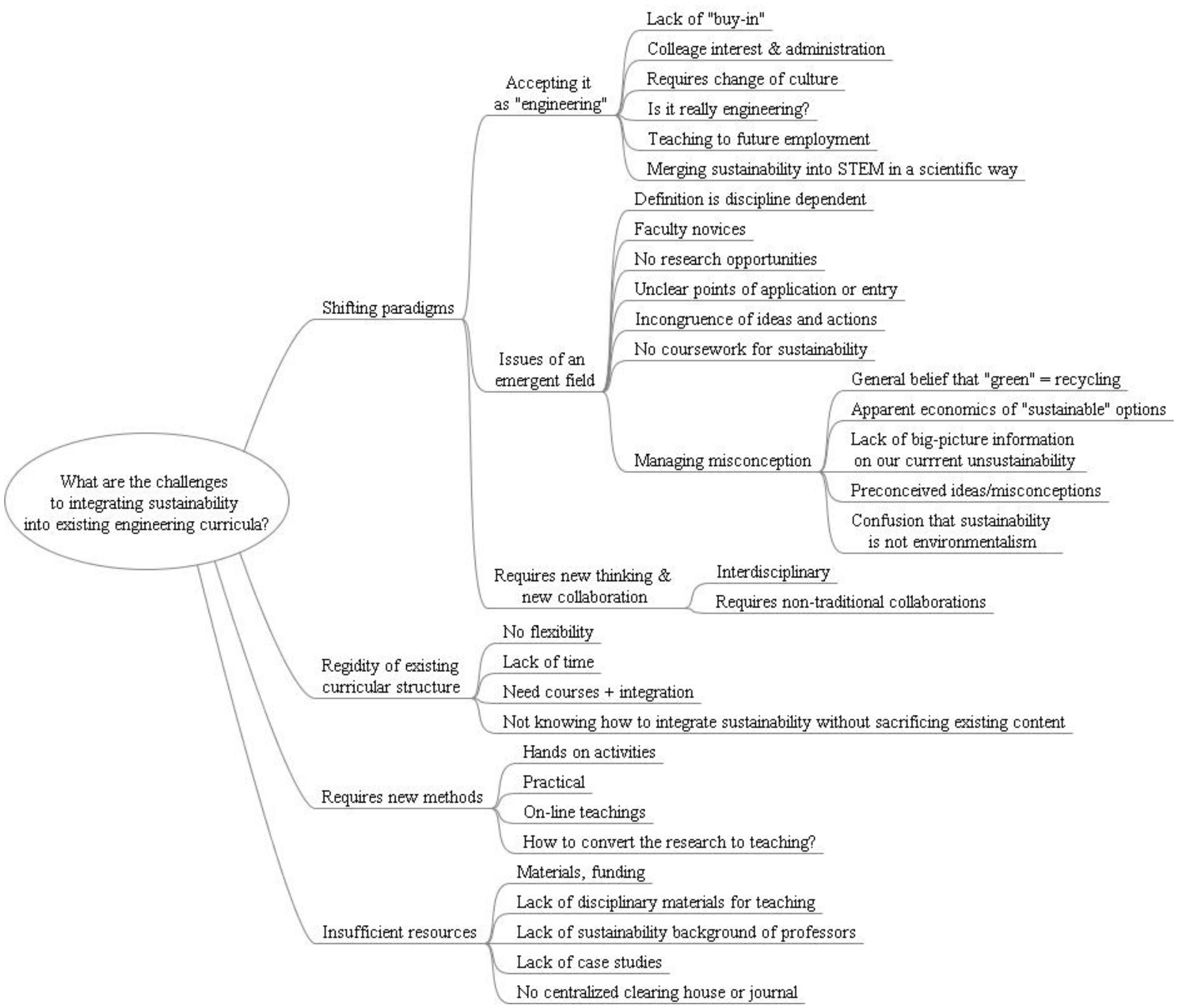

Figure 3. Challenges to integrating sustainability into existing engineering curricular identified by workshop participants.

Interrelationships among challenges

The challenges identified in Figure 3 are not isolated but rather interrelated. For example, new thinking and new collaboration (within the theme of shifting paradigms) will help in developing new teaching methods (within the theme of new methods), effective learning materials, and collaborative research (within the theme of insufficient resources). Such learning materials and research will then develop faculty expertise in the area of sustainability. The interrelationships among these challenges are depicted in a causal loop diagram as shown in Figure 4. A causal loop diagram (CLD) is a systems thinking tool that aids the analysis of interrelationships within a complex and dynamic system[8]. Central to the approach is the idea of feedback loops between components of a system ("positive" feedback loops reinforce the behavior of the system while "negative" feedbacks correct the behavior). Using a CLD can help to identify leverage points where a change in one aspect could have a significant impact on the rest of the system[9]. The relationships between challenges were established either as they were mentioned in literature or from experience of the authors.

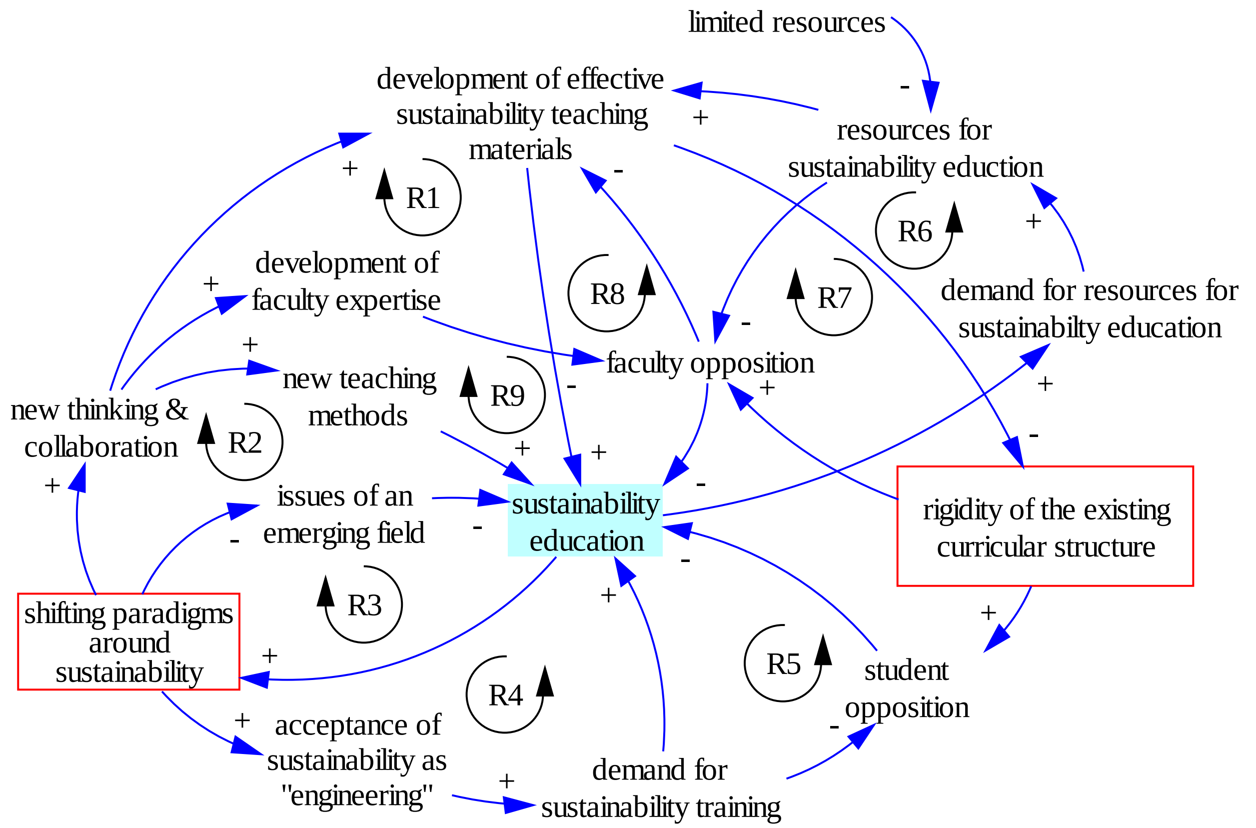

Figure 4. A diagram depicting simplified causal relationships among challenges to integrating sustainability into engineering education. Leverage points are outlined in red. Direct positive (+) or negative (-) causality exists between the variables linked by arrows. R indicates reinforcing feedback loop.

The overall goal is to advance sustainability education. As shown in Figure 4, there are several approaches to achieve this goal, such as increasing the demand for sustainability training, developing new teaching methods and effective learning materials, and reducing faculty and student opposition.

In Figure 4, 9 reinforcing loops (R1-R9) are illustrated as examples and described in Table 1.

Table 1. A description of feedback loops illustrated in Figure 4.

Loops	Description of loops
R1	sustainability education → shifting paradigms around sustainability → new thinking & collaboration→ development of effective sustainability teaching materials → sustainability education
R2	sustainability education → shifting paradigms around sustainability → new thinking & collaboration → new teaching methods → sustainability education
R3	sustainability education → shifting paradigms around sustaina bility → issues of an emerging field → sustainability education
R4	sustainability education → shifting paradigms around sustainability → acceptance of sustainability as “engineering” → demand for sustainability training → sustainability education

R5	sustainability education → shifting paradigms around sustainability → acceptance of sustainability as "engineering"→ demand for sustainability training → student opposition → sustainability education
R6	sustainability education→ demand for resources for sus tainability education → resources for sustainability education→ faculty opposition → sustainability education
R7	faculty opposition → development of effective sustainability teaching materials → rigidity of the existing curricular structure → faculty opposition
R8	sustainability education→ demand for resources for sustainability education → resources for sustainability education→ faculty opposition → development of effective sustainability teaching materials → sustainability education
R9	sustainability education → shifting paradigms around sustainability → new thinking & collaboration→ development of faculty expertise → faculty opposition → sustainability education

Among them, R1-R4 involve shifting paradigms around sustainability; R5 involves both shifting paradigms around sustainability and student opposition which is directly influenced by the rigidity of the existing curricular structure; R6-R8 involves faculty opposition which is again influenced by the rigidity of the existing curricular structure and resources for sustainability education; R9 involves both shifting paradigms and faculty opposition. The loops of R1–R3 show that shifting paradigms around sustainability lead to new ideas in faculty and non-faculty members of the sustainability education community which supports an increase in new thinking and collaboration. New thinking and collaboration opens the door to creativity and exposure in faculty, which supports the development of effective sustainability teaching materials (R1), new teaching methods (R2) and faculty expertise. Effective sustainability teaching materials and methods advance sustainability education and in turn reinforce shifting paradigms. Development of faculty expertise reduces faculty novices to sustainability and consequently reduces their opposition to sustainability education. R3 involves resolving issues of an emerging field through shifting paradigms. These issues are related to the fact that sustainability is an emerging field which has not yet developed its own body of knowledge. Most commonly, the primary issue cited in this area is the lack of a universal definition of sustainability[5,10] and misconceptions due to that (see Figure 3). Resolving those issues will advance sustainability education. R4 involves shifting paradigms which should increase the acceptance of sustainability as engineering (see Figure 3). Sustainability is a complex topic and the heart of sustainable design is the thinking in systems which include not only engineering but beyond it[4]. With an increase in acceptance of sustainability as "engineering" (see Figure 3), demand for sustainability training should also increase, causing an advance in sustainability education. Closely related to R4 is the loop R5 which deals more specifically with acceptance of sustainability education by the student body. Both increasing demand for sustainability training and freeing of the curricular structure will reduce the resistance of students to sustainability education. These six reinforcing loops (R1-5, R9) all involve shifting paradigms and a change in shifting paradigms will affect sustainability education in a reinforcing manner through all these feedback loops.

Both loops R6 and R8 show the approach of advancing sustainability education through reducing faculty opposition caused by limited resources. To develop and deliver sustainability teaching materials requires significant time and effort, which becomes a burden for faculty if there are limited resources and support. To overcome this, we have integrated concepts of sustainability into existing textbooks[11] and developed and disseminated modular materials that can be easily and widely adopted in many engineering courses[12].

Loop R7 does not directly involve sustainability education, but it contains faculty opposition which directly influences sustainability education. Rigidity of the curricular structure is a factor which will increase faculty opposition and consequently decrease the development of effective sustainability teaching materials. Without effective teaching materials, sustainability cannot be strategically integrated into the existing curricular structure and can make the current curriculum more crowded and reinforce the rigidity of the curricular structure. Additionally, as curricular rigidity typically increases student opposition as the general acceptability of sustainability education decreases when it is viewed as a non-essential topic in engineering[4]. Rigidity of the curricular structure has, therefore, been deemed an important factor in the causal relationships that affect sustainability education via several different pathways (e.g., R5- R9).

Proposed strategies

The higher leveraged interventions are in the area of shifting paradigms and freeing curricular structure. In the area of shifting paradigms, in order to advance sustainability education, the need for government interventions in the form of a clear national development policy has been proposed[3,4,10]. The proposed solutions also include standardization of sustainability competencies by the engineering accreditation organization (i.e., ABET)[13]. Clarifying and solidifying sustainability competency standards are also expected to affect the curricular structure at the institutional level which would drive sustainability education in typical engineering education[13]. To address the need for sustainability education without revamping the current engineering curricula, some have suggested teaching sustainability classes to gifted undergraduate students or offering sustainability tracks at the graduate level[14].

Another higher-leverage intervention in the area of shifting paradigm would be faculty's development in understanding of sustainability. During the workshops we discovered that faculty consistently expressed a need for their personal development in their understanding of sustainability in order to integrate the concepts into their classroom. As mentioned previously, workshop participants consistently identified themselves as "novices" in the area of sustainable design, with self-identification of teachers ranging from novice to expert. Therefore, development of a low-barrier means for faculty to educate themselves would be a leverage intervention to advance sustainability education.

In addition, institutional change such as merging some academic engineering departments is a leverage strategy for sustainability education. Such academic departments can not only share financial and material resources but also facilitate the development of faculty expertise development and stimulate new collaboration[5].

Conclusions

The challenges to integrating sustainability into existing engineering curricula have been identified through 2 workshops. The identified challenges were organized by the workshop participants into four major areas: (1) shifting paradigms around sustainability; (2) the rigidity of the existing curricular structure; (3) requirement of new teaching methods; and (4) insufficient resources. Such challenges were analyzed in this paper through a system approach using causal loop diagram. It was found that the great challenges are not technological but those involving the human system, such as “accepting sustainability as engineering”. The higher leveraged interventions are in the area of shifting paradigms and freeing the curricular structure. The strategies that could effectively advance sustainability education include: a clear national development policy, standardization of sustainability competencies by the engineering accreditation organization, development of a low-barrier means for faculty education, and merging of academic engineering departments.

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