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Transdisciplinary Approaches for Teaching and Assessing Sustainable Design*

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Sustainable design can be defined as incorporating larger environmental, resource, and social issues into decisions of the conceptualization, design, manufacture, operation, and end-of-life of products and systems. These larger issues include, for example, environmental concerns, energy independence, economic viability, and social impact. This paper argues for the need for transdisciplinary approaches for teaching and assessing sustainable design for undergraduate engineering curricula. These transdisciplinary approaches are discussed in the context of application to traditional senior- and freshman-level ('capstone' and 'cornerstone') design projects and incorporation into innovative technology programs that provide outreach and seamless pathways for recruiting engineering students and developing a sustainable workforce.

The teaching and assessment of sustainable design concepts and approaches should be driven by social and industrial needs while addressing forward-looking issues including the design and development of innovative products and service systems that use dramatically less energy, the reduction of energy intensity in manufacturing, and the provision of energy using 'green' technologies. The sections of this paper cover transdisciplinary design; sustainable design projects for undergraduate education; and pathways for a sustainable engineering and technology workforce.

Keywords: sustainable design; transdisciplinary design; undergraduate education; seamless technology program

1. TRANSDISCIPLINARY DESIGN

DESIGN MAY BE characterized 'as the epitome of the goal of engineering [that] facilitates the creation of new products, processes, software, systems, and organizations through which engineering contributes to society by satisfying its needs and aspirations' [1]. Design can be a challenging subject to teach because 'design thinking' is characterized by a set of skills that include tolerating ambiguity; viewing from a systems perspective; dealing with uncertainty; and using estimates, simulations, and experiments to make effective decisions [2, 3].

Sustainability as applied to engineering design is perhaps best understood in terms of energy resources, environmental issues, economic factors, and social impact. Energy consumption in the U.S. can be divided into three roughly equal sectors: buildings, transportation, and manufacturing [4]. It is difficult for individual engineers to be conversant with the many technological, social, and economic focuses bearing on new designs, and it is also difficult for engineers to define the right problems to be addressed [5]. Radical, transdisciplinary approaches are needed for product conceptualization, development, and business models that incorporate environmental profiles, manufacturing processes, emissions, and resource consumption to achieve order-of-magnitude improvements [5–9].

Today the need is for a 'transdisciplinary' education and research model that can transcend traditional disciplinary or organizational boundaries to enable the solution of large problems by teams of people from diverse backgrounds. While the terms are contested in the literature, *transdisciplinary* is intended to go beyond *multidisciplinary* (involving several disciplines in examining a shared topic) and *interdisciplinary* (borrowing a research method from one discipline to use in another). [5–7, 10] 'Multidisciplinary approaches juxtapose disciplinary/professional perspectives, adding breadth and available knowledge, information, and methods. They speak as separate voices, in encyclopedic alignment . . . Interdisciplinary approaches integrate separate disciplinary data, methods, tools, concepts, and theories in order to create a holistic view or common understanding of complex issues, questions, or problems' [11]. 'The transdisciplinary concept is a process by which researchers representing diverse disciplines work jointly to develop and use a shared conceptual framework. This shared framework draws together discipline specific theories, concepts and methods to address common problems' [12]. In this process, a new synthesis of a common ontology of concepts,

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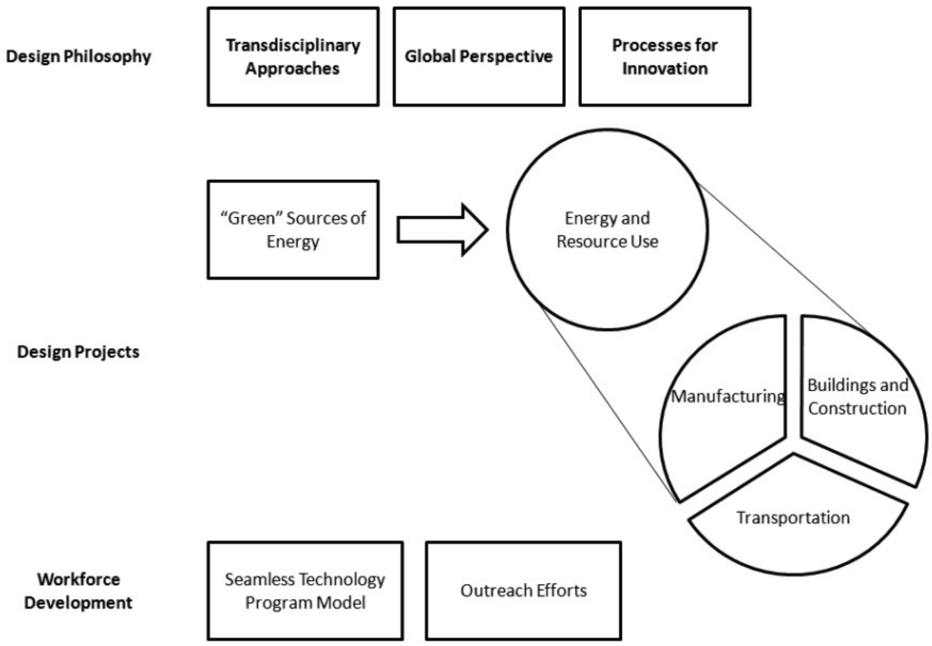

Fig. 1. Elements of undergraduate education in sustainable design covered in this paper.

scope of inquiry, theories, and methodology is created. Recent efforts within engineering education to promote inter/transdisciplinary collaboration in engineering include, for example, [13, 14]. Figure 1 identifies elements of an undergraduate program in sustainable design.

2. SUSTAINABLE DESIGN PROJECTS FOR THE UNDERGRADUATE EDUCATION

Educational programs in innovative and sustainable design have been carried out at Texas Tech University in conjunction with research activities to develop graduates who have a substantial understanding of the need for sustainability and a working knowledge of engineering design, innovation, product development, and product commercialization. Design courses have been developed for three levels—freshman, senior, and graduate.

A growing number of engineering curricula are introducing freshman-level 'cornerstone' design courses to complement the traditional senior-year 'capstone' design sequence [2]. The freshman-level sustainable design course developed by faculty in the College of Engineering at Texas Tech University was first offered in Fall 2008. This course introduces students to engineering in general, engineering design processes, energy and resource use, and environmental responsibility. It also helps students learn to think creatively, work effectively in teams, and solve problems. The course shows that what may appear to be a problem is also an opportunity for change. Technical concepts, which emphasize vehicle and building technologies, for the pilot course, are presented in lecture and discussion formats and reinforced through projects and laboratory work. The Advanced Vehicle Engineering Laboratory in the College of Engineering and a sustainable building technology laboratory (the Sustainable Cabin discussed below) being developed in the College of Architecture provide facilities for laboratory experiences. In addition to the responsible faculty, speakers from academia, government, and industry also participate. The course is open to any student in the university and is dual-listed with South Plains College to provide a direct outreach effort to community college students. This course provides students the opportunity to

- Develop creative and critical thinking processes—the design process begins with synthesis of ideas followed by analysis of those ideas, usually in an iterative process.
- Develop an understanding and appreciation of the need for sustainability—sustainable design is based on minimizing resources consumed by the manufacture, use and disposal of products and the utmost respect for the environment.
- Learn and apply engineering design processes to develop sustainable products and systems—the world's population continues to increase, thus, resources must be managed to provide a sustainable environment.
- Appreciate that opportunities for a sustainable future abound—the future will be what mankind, through creativity and innovation, designs it to be.
- Develop a compelling desire to question and to learn to provide a basis for change—it is not sufficient for engineers to merely respond to needs, they must continuously seek opportunities to introduce changes that provide sustainability.

Table 1. Example senior-level capstone design project topics in sustainable design

Sustainable energy	Building technology	Automotive technology	Manufacturing
Wind turbine gearbox.	Sustainable cabin.	FutureTruck.	Fiberglass pipe lining manufacturing system.
Wind turbine maintenance & reliability.	Solar-powered radiant heating.	ChallengeX.	
Wind turbine energy storage.	Building thermal analysis.	EcoCar challenge.	
Bio-mass char production.	CEB building system.	Model T pickup electric conversion.	
Wind turbine for oilfield applications.	Pivot irrigation system refurbishment.	Variable orbital aperture.	
Wind turbine desktop generator.	A/C for commercial building.	Hybrid HMMWV.	
Gassifier.			

In the senior-level course, student teams design specific products, processes, or systems associated with sustainable energy production, sustainable buildings, transportation, and manufacturing systems. Materials related to energy, efficiency, environmental issues, economics, innovation, product commercialization, creativity, etc, are provided through discussions, lectures, guest speakers, and readings. Most of the projects assigned are related to on-going research projects or are initial concepts that will become the basis for new research projects. Assessment methods include topical research papers, team design projects, and oral and written presentations of project results. Table 1 lists example senior-level capstone design project topics from the last three years, involving students from mechanical engineering as well as other disciplines including architecture and electrical engineering. The objectives of representative projects in each category will be described in more detail below.

The graduate course extends the senior course and provides a design elective for graduate students and advanced undergraduates. This course requires more reading assignments and literature research, and project teams are required to explore commercialization possibilities and intellectual property protection for their designs. A graduate course in innovation, tentatively titled *Transdisciplinary Discovery and Innovation for Engineers*, that surveys innovation from a transdisciplinary perspective while integrating contributions from engineering design was piloted in Fall 2007 with PhD students.

At both the undergraduate and graduate level, a case-study approach has been used in the classroom based upon lecture and facilitated discussion. An example of this approach has been teaching based upon the Huangbaiyu eco-village in China. Students are shown a video of the project, in three parts [15–17]. The topics of discussion include requirements definition, stakeholder roles and responsibilities, and evaluation of sustainability for the proposed versus current village lifestyles. The case raises issues among three aspects of sustainability: economic, environmental, and especially social. Exploration and understanding of the case requires the students to consider disciplines other than engineering and to recognize failures at the interfaces between these disciplines. Moreover, the case is useful for raising the students' awareness of local context (a foreign country with which most of them are not familiar) and the importance of understanding the end users. While a proposed solution may be technologically feasible, if the end users will not accept it, the project is a waste of time, effort, and money.

2.1 Green sources of energy

Solar, wind, and geothermal energy sources are usually considered to be green and renewable. Green and sustainable energy sources are not dependent on diminishing resources, generate minimal emissions, and consume minimal water during production and transportation or transmission. The vehicle industry applies a 'well to wheels' concept—the total energy consumed and emissions generated by fuel production, processing, and transportation and by vehicle design, manufacturing, and direct vehicle consumption. Similar energy accounting should be applied for all product design, manufacturing, and utilization.

2.2 Manufacturing

During the process of converting resources into products, materials, manufacturing processes, product usage, and end of life, waste is the source of conflict created between the environment and development. Global research activities in sustainable manufacturing address this conflict through technologies, methodologies, and systems. The environmental impact and efficiency of resource use are considered via information technology to (1) minimize the rate of resource use from product design, manufacturing, operation, and recycling of spent materials until the end of the life cycle; (2) lower energy consumption; and (3) minimize or prevent environmental pollution while achieving the economic success of enterprises and optimizing the provision of social benefits. Creating a sustainable human society requires the strategy of sustainable development and a recycling-intensive economy for the modern manufacturing industry. The realization of the basic idea is to implement a manufacturing product life cycle that minimizes resource consumption and environmental pollution while maximizing human safety, health hazard reduction, efficient resource use, and resource renewability. The theory of sustainable manufacturing systems, tools, and support for applications will be a major research and education field of the 21st century [18–21].

2.3 Buildings and construction

The objective of sustainable building technology projects is to dramatically decrease energy consumption at lower construction cost as compared with conventional building and to foster sustainable growth by reducing the embedded energy and material resources for building construction and by minimizing ecological impact of building systems. According to the US Department of Energy in 2005, 40% of the total energy consumption in the United States was used for residential and commercial buildings, representing a cost of $370 billion. 23% of the building energy consumption was for heating; 18% was for lighting; 13% was for cooling; and 7% was for water heating [22]. In addition to the 40% of US primary energy consumption in the building sector, a complete picture of building energy use must account for the embedded energy consumed by harvesting, mining, processing, manufacturing, and shipping associated with creating the built environment.

Currently, the US imports 13.5 million barrels of oil per day [23]. The national dependence upon limited, foreign oil and gas resources needs to be reduced—part of the solution is to move toward more energy-efficient buildings. In addition to economic costs, there is a growing national sensitivity to environmental issues associated with buildings. For a typical 2,000 square foot home, 4 tons of waste are generated [22]. Wood-framed housing accounts for ninety percent of all new home construction in America [24]. Thus, buyers of new homes have little choice but to buy wood-framed houses. Due to higher construction costs, only the wealthy can afford homes that use superior construction materials.

2.3.1 Sustainable cabin

Project description: The Sustainable Cabin Project is a collaborative project between the College of Architecture and Department of Mechanical Engineering at Texas Tech University. Students and faculty teamed in the academic year of 2008/2009 to design and build a sustainable cabin. There are a number of building materials and products that, when used properly, can be components within a larger system of sustainable architectural design. These products include—but are not limited to—solar technology, composting toilets, and rainwater harvesting devices. These products are available to consumers nationwide, but how many are suitable to the particular environmental conditions of West Texas? Under this project, stock products, in addition to new, readily available products, are tested for their potential for sustainable construction in West Texas.

Transdisciplinary focus: The project is part of an elective course in Architecture ARCH 5302 and the senior capstone design sequence in Mechanical Engineering ME 4370 and ME 4371. The students work on the project within the framework of their respective disciplinary courses; however, they are jointly conceptualizing and building the physical cabin. This project will result in construction of a 'Prefabricated Dwelling.' Once completed the cabin can serve as a laboratory—itself designed as a model of sustainability—that will be used to test and demonstrate sustainable architectural concepts. Upon completion, the cabin will provide a hands-on laboratory for architecture and engineering students to learn about sustainable building materials and components. For example, the performance of a solar panel will be tested and measured, and the data collected will be compared to the performance of competing products. In that way the prefabricated dwelling as a laboratory will produce data on sustainable components, materials, and water harvesting technology that will help future architects and engineers to make crucial and lucrative design decisions and help them to envision how to construct new homes or retrofit existing homes with sustainable technology. To realize the concept of sustainability in a building system requires knowledge from multiple disciplines, such as calculation of thermal performance from mechanical engineering to determine heating and cooling loads and the use of contextual architectural features to promote solar heating in winter and facilitate ventilation for cooling in summer.

Teaching philosophy and practices: The students' most immediate benefit is to be exposed to each other's discipline within a project that will become real. Architecture and mechanical engineering students working side by side design-build the cabin in a nearby warehouse. In the eyes of the instructors it is important to expose the students to each other's discipline. In the time of specialized training and expertise, the collaboration forces the people involved to listen and be open to each other's expertise. While architecture students with their education in materials and tectonics can explain and detail the construction, mechanical engineering students calculated the heating needs for the Sustainable Cabin and made proposals for a simple solar-heated warm water system. The students must integrate the knowledge of their respective disciplines into a system that fulfills the objectives from both an architectural and an engineering standpoint. So far what the students from both disciplines have learned is the respect for each other's work, the need for the exchange of ideas, knowledge of where each discipline is coming from, and also, not to underestimate, the learning and understanding of materials. Once a concept, such as building a water pumping system, is drawn up, it has to be built, implemented, and installed in the structure. The resistance that comes

Fig. 2. Architecture and mechanical engineering students working on sustainable cabin project.

with this is real and not another abstract exercise or calculation on paper.

2.4 Automotive systems

2.4.1 EcoCar outreach

Project description: Professional Communications for Engineers is a general course open to all students in the College of Engineering. Although the focus of the course is to introduce students to written, oral and internet communication, a subfocus of the course is to introduce students to the engineering design process. The course is a service-learning course [25, 26] that ties civic involvement to course design. For two semesters, students have worked with the Texas Tech EcoCAR Challenge [27], a Department of Energy (DOE) competition that involves seventeen universities. The challenge for engineering students at the seventeen universities is to design a vehicle that will meet all the requirements for a sustainable energy vehicle and will still be safe and comfortable to drive through redesigning a Saturn Vue. The rating scale for the competition includes 25 points for outreach, which includes marketing and educational outreach. Students in the Professional Communications course are focusing on the education outreach component of the design. These students design hands-on activity kits that will introduce K-12 teachers and students to the EcoCAR challenge. In addition, some of the students are designing information displays for the adult community for trade shows and community events. An example of the students' designs include a hydrogen-fuel cell kit, a solar-powered model car, a demonstration of a lithium cell battery, and other projects that demonstrate sustainable energy fuels.

Transdisciplinary focus: Students in the Professional Communications for Engineers course get firsthand experience working with a client, in this case, a civic organizational client, and they learn how to work in diverse teams. Because the student body of the class is made up of students from Industrial Engineering, Civil Engineering, Electrical and Computing Engineering, and Mechanical Engineering, as well as undecided students, the teams are composed of students from diverse disciplines. This gives students the opportunity to work with people in disciplines other than their own. A valuable part of the project is that students have to learn about sustainable design in relationship to sustainable fuels. A goal for the Professional Communications for Engineers course is to educate the K-12 community and the adult community about sustainable technologies and to encourage K-12 students to seek careers in engineering. Working with K-12 teachers and students for over ten years, the professor of Professional Communications for Engineers knows, first-hand, how little the K-12 community knows about sustainable energy and the engineering design process. Having to design hands-on activity kits for an audience that is out of the College of Engineering students' purview, challenges them to think beyond their own classroom experience in order to do research into sustainable energy and sustainable design as well as what K-12 students are expected to learn at different grade levels according to the Texas Education Agency standards.

Teaching philosophy and practices: Once given the class criteria for developing the activities for K-12 and the community, Professional Communications for Engineers students must research sustainable energy, design a hands-on activity that is grade-appropriate, and write a proposal to the Texas Tech EcoCAR Challenge Team. Once the proposal is accepted by the team and the professor, students write extremely detailed descriptions of the 'product' that is submitted to the EcoCAR Challenge team—the hands-on activity, instructions on assembly and/or on the process, and a final report that encompasses previous documents and is acceptable as a professional document submitted to the EcoCAR Challenge team and that will live with the hands-on activity kits. A service-learning project introduces students not only to working with teams, but also to the reality that there are no easy quick answers to addressing a problem or requirement. Clients might reject a design or might require that proposed concepts be altered to better fit the client's needs. Engineering students learn that engineering design is more involved than just deriving a solution [28]. Although the evaluation criteria is centered on communication skills, students must apply the engineering design process in order to problem-solve the needs of the community client. Addressing the design process as well as the challenges of designing for a client, and in this case looking at the challenges that society is currently facing and will face over the next couple of decades with sustainable energy, provides students with real-world experience while learning the engineering design process and the role the engineers play in society.

2.4.2 MATLAB Simulation for vehicle performance

Project description: A main goal of this project is to develop a graphical user interface (GUI) based on MATLAB for students from different levels (such as those enrolling in the freshman-level sustainable design course) that can facilitate their understanding of factors that can affect vehicle performance. Vehicle acceleration performance is not only a key performance index, but also greatly affects fuel efficiency because a vehicle can seldom remain at a constant speed when traveling an urban environment. Thus, understanding acceleration performance and optimizing it to achieve better fuel economy is a challenging task. This GUI helps students to visualize how factors such as vehicle mass or tire size will affect acceleration performance. Although students may have no prior knowledge regarding vehicle performance or the fundamental equations behind it, they gain practical experience by adjusting parameters and viewing simulation results.

Another part of the project is to calculate fuel efficiency of a vehicle following a drive cycle. Drive Cycle Recognition (DCR) is an advanced vehicle-control strategy that uses past driving information, as well as a library of representative drive cycles to extrapolate future vehicle control parameters. In this simulation, an Urban Dynamometer Driving Schedule (UDDS) drive cycle was adopted, and the vehicle is a series hybrid in which both an electric motor and a diesel engine are used. The diesel engine will supply power to the electrical motor and charge the battery as needed. Students can also alter some parameters such as transmission ratio or aerodynamic co-efficient to see how they will affect fuel consumption. The simulation not only shows whether the vehicle can follow the desired drive cycle, but also indicates how much gas is actually consumed during traveling (Fig. 3 and 4).

Teaching philosophy and practices: For teaching sustainability in the context of automotive technology—such as in the Seamless Automotive Program described below—class discussions of engine performance can be enhanced by laboratory experiments that allow students to measure vehicle, engine, and other component performances with engine and chassis dynamometers and other test equipment. MATLAB/Simulink simulations allow students at all three levels to explore engine and vehicle level systems integration and control

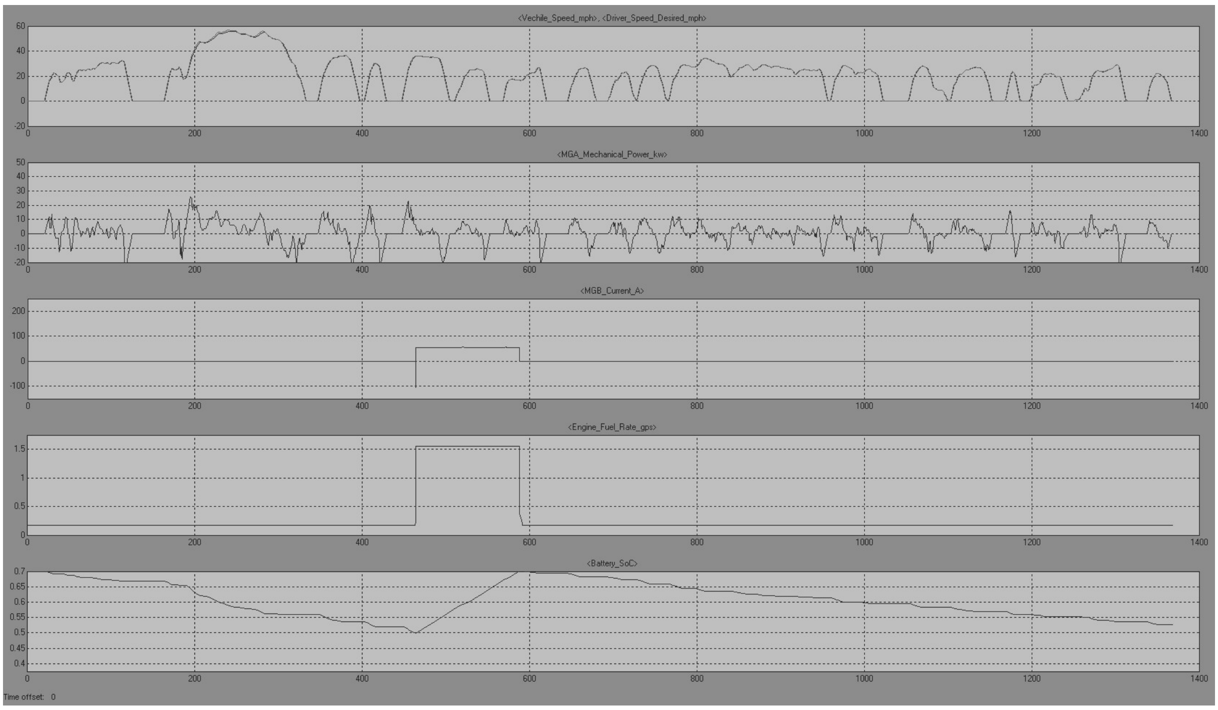

Fig. 3. Simulation result—following the drive cycle.

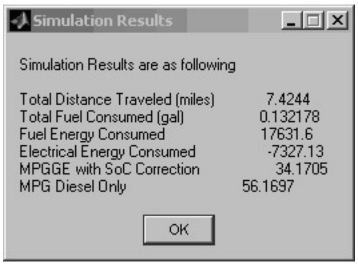

Fig. 4. Simulation result—fuel consumption.

strategies. The simulation activities provide students with an understanding and appreciation of model-based design. The simulation models are currently being developed by seniors and graduate students at TTU. The simulation models themselves can be used as teaching aids, at multiple levels of instruction, with added depth and complexity to match the students' backgrounds. The students who use the simulations develop an appreciation of thermodynamics, fluid mechanics, as well as social factors in driver operation that influence the ultimate fuel consumption of the vehicle. As a project topic, the development of the models requires the student(s) to understand both the technical content behind the simulation as well as the educational objectives and the users' expectations in controlling and adjusting the models.

3. PATHWAYS FOR A SUSTAINABLE ENGINEERING AND TECHNOLOGY WORKFORCE

Students currently in college and those entering college will develop and implement solutions to challenges that society faces over the next 20 years [29–31]. In particular, tomorrow's engineers need to be able to think creatively and critically to make effective use of energy resources and synthesize sustainable technologies. As part of this challenge, attracting and retaining a larger, more diverse pool of engineering students remains one of this country's pressing needs, and once students have embarked on a course of engineering study, the development of skills in design remains an important yet challenging task.

Our technology-driven society has led to the development of many new careers and occupations and to the loss of many others. Approximately 50% of the 20,000 careers which exist in the US today did not exist 30 years ago, and 50% of the careers of the 1970s do not exist today [32]. Educational processes are expected to change significantly over the next 20 years in an effort to better prepare students at all levels to pro-actively meet the challenges of their changing world. Traditional K-12 schooling will likely evolve into a mix of in-class, online, at-home, and self-paced instruction with an emphasis on acquiring skills to foster innovation to keep pace with ever changing technology. Educational curricula from elementary school through college will be developed jointly by business and academia to prepare students academically, technically, and socially [33]. Students completing educational programs and entering the workforce must learn to embrace change as opportunity.

South Plains College (SPC), the College of Engineering at Texas Tech University (TTU), the Lubbock Independent School District (LISD) and the Lubbock Economic Development Alliance (LEDA) partnered to develop a seamless automotive curriculum around a new educational model [34, 35]. This program provides a novel model for outreach and recruiting of future engineers and technicians and especially reaches groups that have traditionally been underrepresented in engineering and technological disciplines. The model is innovative in providing a three-tier program linked through articulation agreements that implicitly integrates math and science with applied learning activities and provides career-path flexibility to the students. Flexibility provides options for students to leave the educational process at various points and join the workforce with the knowledge and skills needed to be competitive at that level or continue to higher levels of the educational process. This model is currently being expanded to include other technological areas relevant to sustainable design including advanced manufacturing. Figure 5 shows the structure of the new model for educating automotive technicians and engineers.

The program also provides further enhancements to current educational endeavors including coordination of laboratory experiences at all three levels to directly support and reinforce classroom studies and generate student enthusiasm; involving LISD students in dual credit laboratories at SPC and TTU; allowing LISD and SPC students and faculty to participate in TTU vehicle research projects; and specifically emphasizing creativity, critical thinking, and team work. The seamless curriculum is documented in an articulation agreement between LISD, SPC and TTU [35]. Figure 6 presents a schematic of the seamless automotive curriculum.

Various vehicles, including stock vehicles, alternatively fueled vehicles, hybrid vehicles, etc. are available at the SPC automotive laboratories and the TTU Advanced Vehicle Engineering Laboratory (AVEL). These vehicles and associated spare components provide resources for in-depth design and development projects. Classroom activities are designed to engage students' curiosity and promote critical thinking. In addition to concentrated STEM content, classroom activities promote creativity, library and internet research, team work, and communications skills. LISD and SPC students and faculty work with graduate and undergraduate students on vehicle related research and design projects at the TTU AVEL. Students participating in design and research projects are

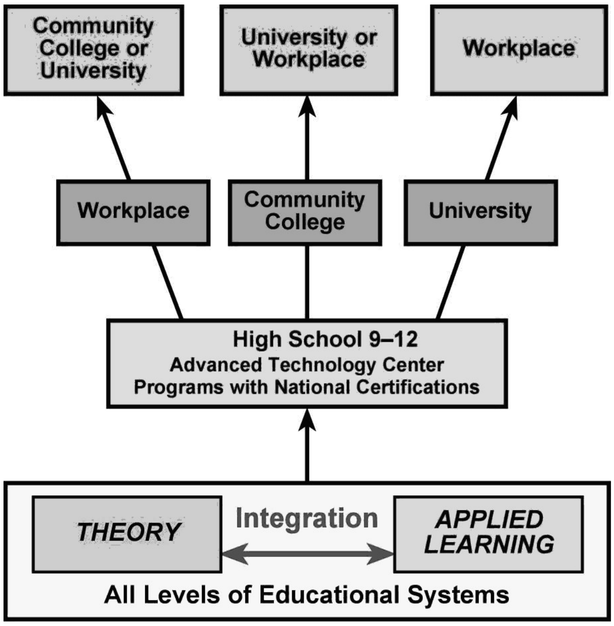

Fig. 5. Model for integrated and flexible educational process.

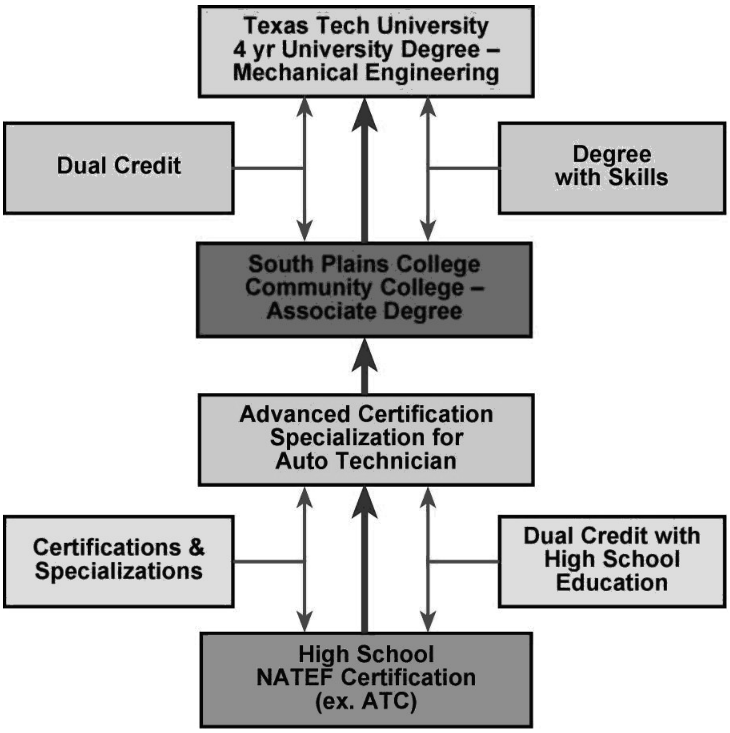

Fig. 6. Integration of theory and applied learning at all levels.

selected by LISD and SPC faculty. Program benefits include the following:

- Local workforce increased with high quality, skilled automotive technicians.
- Students have a flexible program which allows selection of desired career level.
- LISD and other high school automotive programs recognized as college prep.
- SPC and TTU programs increase student diversity and retention.
- Students benefit immensely from the combination of hands-on and theoretical work.
- Students from families with little or no prior higher educational experiences will be encouraged to enter 2-year and 4-year college programs.

3.1 Program evaluation plan

Project goals, objectives, measurable indicators, and responsible persons for the assessment activities are summarized in Table 2.

Table 2. Program evaluation plan

Goal	Objectives	Measurable indicators	Responsible persons
Goal 1: to attract bright, energetic, creative young men and women into engineering in general and the automotive industry specifically by providing a flexible educational pathway which incorporates intensive hands–on laboratories to exemplify and extend theoretical studies.	• To improve the recruitment and retention of students, especially students from traditionally underrepresented (women and minority) groups. • To make use of a recent articulation agreement providing educational pathways leading from LISD to SPC and then to TTU and to include additional secondary school systems.	• # of High School students, particularly female and minority, participating in the program. • # of students, particularly female and minority, enrolled in and completing the AAS program in SPC. • # of students, particularly female and minority, enrolled in and completing the Undergraduate program of Mechanical Engineering at TTU. • # of students, particularly female and minority, enrolled in and completing the Graduate program of Mechanical Engineering at TTU.	Staff of LISD, SPC, and College of Engineering at TTU.
.	• To developing life–long career and educational pathways for technicians.	• Science Interest Survey. • Focus Group discussion.	Course instructors and assessment personnel.
.	• To provide financial assistance to qualified students who would otherwise not be able to participate in post secondary educational programs.	• # and amount of scholarships awarded to students, especially students as the first generation of the family to attend college.	Staff of LISD, SPC, and College of Engineering at TTU.
Goal 2: to enhance the curricula—LISD, SPC, and TTU levels—with innovative and stimulating classroom and laboratory learning experiences.	• To ensure rigorous STEM content is included across the curricula of the program.	• Documented curriculum materials developed for LISD, SPC, and TTU approved by the Advisory Board consisting of representatives of academia and industry.	Course instructors at all levels.
.	• To provide students team-building skills and team project experiences.	• Products of team projects evaluated by instructors and industrial experts.	Course instructors and industrial experts.
.	• To incorporate work–based experiences.	• Field–based instructional activities.	Course instructors.
.	• To develop and use appropriate assessment methodologies to measure student learning.	• Test measuring student comprehension of course content. • Projects assessing student skills. • Questionnaire measuring student attitudes toward engineering and sustainable design. • Critical thinking.	Course instructors and assessment personnel.
.	• To address knowledge, skills, and competencies required by modern technical workplaces.	• Student performance on standardized tests and tests of courses. • Student performance on solving real problems. • Critical thinking skills measured by Watson–Glaser Critical Thinking Appraisal or California Critical Thinking Skills Test.	Course instructors and assessment personnel.
Goal 3: to incorporate significant input provided by industry and regulatory agencies.	• To integrate workplace competencies based on industry standards into the curricula.	• Creating entities on metrics evaluating curricula and program effectiveness to ensure the curricula are aligned with industry and accreditation standards.	Course instructors and advisory board.
Goal 4: to provide teachers and instructors, especially those in public school systems, with materials, experiments, and exercises that can be included in classes to emphasize STEM content and concepts of sustainable design.	• Developing innovative laboratory experiences that utilize current instrumentation and are designed to demonstrate and reinforce theory and basic principles.	• Instructional materials designed for lab activities that enhance student understanding of theories and basic principles.	Course instructors and advisory board.
.	• To provide educators training and professional development.	• Training sessions and workshops design for educators. • # of workshop participants.	Training organizer & assessment personnel.

4. CONCLUSIONS

In this paper the authors have introduced a framework for a program in innovative and sustainable design focused on energy, transportation, building, and manufacturing technologies. The authors argue for the need of a transdisciplinary research and educational framework to address the sustainable design of modern engineering systems and to prepare the engineers, designers, and researchers of the future.

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