A Transdisciplinary Research Approach to Engineering Education

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Abstract

This paper analyzes a transdisciplinary (TD) research approach to undergraduate engineering education in an effort to examine alternative learning theories and consequently, to improve STEM learning outcomes. Recent studies suggest engineering education must evolve to teach a more holistic approach to problem solving in order to prepare students for the growing complexity of problems inherent in today’s society; and transdisciplinarity directly addresses this need. Transdisciplinary approaches engage students in collaborative, cross-disciplinary exercises with both students and domain experts, while simultaneously utilizing trandisciplinary models for processing information and methodologies designed to elevate students’ critical skills. The expected results of TD research and education are: emphasis on teamwork; bringing together non-academic experts and academic researchers from diverse disciplines; developing and sharing of concepts, methodologies, processes, and tools; all to create critical and integrated engagement by students and professionals.

While researchers have become accustomed to working across disciplinary boundaries, the undergraduate classes offered by many universities have been the same for decades. Undergraduate students should master TD competencies before they go on to graduate studies or employment. Students need to be strengthened and prepared to create, and become a contributing
member of multiple communities of knowledge and communities of practice. Transdisciplinary teaching pedagogies aid in that goal.

The present paper explores ways of integrating TD approaches into the curriculum. The authors focused on the development of TD skills and TD research processes as part of curricula and pedagogical strategy. They highlight the preliminary results of use of TD methods across the engineering curriculum, use of TD methods in distance learning, and also explore the use of internet textbooks (iTextBooks) focused on TD methods.

**Introduction**

This study is aimed at a wide audience of senior engineering design classes that cut across multiple fields. In keeping with the dynamic nature of complex problem solving, modern educational curricula must be designed to enhance STEM learning while helping students develop critical thinking and problem-solving skills related to a broad spectrum of disciplines. This paper explores ways of integrating TD approaches into the curriculum. The transdisciplinary approach is critical for improving STEM learning because the approach advocates for cross-disciplinary, collaborative, and problem-solving based tasks for learning. This paper also presents an alternative to conventional textbooks in the form of a free, internet-textbook (iTextBook) composed of nine fundamentals of design modules and four TD learning modules that cut across multiple disciplines.

New approaches are needed for educating engineering students. Many companies and industries have found that several tasks of engineering, innovation, and development can be performed more cheaply and efficiently overseas. With information technology and globalization, STEM dominated fields are being outsourced [1]. In one widely publicized estimate, Forrester Research estimates that 3.3 million R&D jobs will move offshore by 2015 [2]. This means U.S. students will require value-added skills [3] — namely creativity, problem definition and innovation, and integration of engineering systems [4]. In addition, they need to be able to grapple with the technological challenges and opportunities in today’s world.

**Challenges in Engineering Education**

In a recent article in the *Chronicle of Higher Education*, Grasso and Martinelli, address challenges brought forth in *Rising Above the Gathering Storm* [5]. They conclude that the U. S. does not necessarily need more engineers but rather needs to maintain the quality of 21st century engineering graduates and to educate engineers in a more holistic manner. Engineers should “look beyond the fields of math and science, in search of solutions to entire problems,” and “must at least attempt to understand the human condition in all its complexity—which requires the study of literature, history, philosophy, psychology, religion and economics, among other fields” [6]. There is a current need to re-emphasize the creative aspects of engineering innovation to maintain competitiveness and to prepare future engineers and researchers for a global environment [7]. U.S. students need to be taught new skills for *dynamically synthesizing new knowledge* in response to challenges they will face, such as the Grand Challenges identified by the National Academy of Engineering [8] and new challenges not yet recognized.
Interdisciplinary and Transdisciplinary

Transdisciplinarity can be defined as the practice of acquiring new knowledge through education, research, design, and production with a broad emphasis on complex problem solving. The goal of transdisciplinary practice is to improve students’ understanding of complex issues by extracting the valuable aspects of typical academic disciplines and thereby generate both a more integrative and universal solution to support an issue of importance to society. The field of transdisciplinarity began in the early 1970s \[9, 10\]. Many scientists and engineers made excellent contributions to the development of a transdisciplinary methodology over the years. An interdisciplinary (ID) methodology has been defined as “two or more disciplines which combine their expertise to jointly address an area of common concern” \[11, 12\]. “Interdisciplinary approaches integrate separate disciplinary data, methods, tools, concepts, and theories in order to create a holistic view or common understanding of complex issues whereas transdisciplinary approaches are comprehensive frameworks that transcend the narrow scope of disciplinary world views through an overarching synthesis \[13]\”. TD research includes cooperation within the scientific community and a debate between research and society at large. TD research therefore transgresses boundaries among scientific disciplines and between science and other fields and includes deliberation about facts, practices and values \[14\].

Cronin stated, “There is a need for transdisciplinary research (TR) when knowledge about a societally relevant problem field is uncertain, when the concrete nature of problems is disputed, and when there is a great deal at stake for those concerned by problems and involved in dealing with them. TR deals with problem fields in such a way that it can: a) grasp the complexity of problems, b) take into account the diversity of life world and scientific perceptions of problems, c) link abstract and case specific knowledge and, d) constitute knowledge and practices that promote what is conceived to be the common good.” \[15\].

Transdisciplinarity promotes “theoretical, conceptual, and methodological reorientation with respect to core concepts of the participating disciplines \[16\]”. The expected result of TD education is creative potential of cross-disciplinary collaborative research -- ways to solve challenging contemporary social issues. The TD approach teaches students to seek collaboration outside the bounds of their professional experience to make new discoveries, explore different perspectives, express and exchange ideas, and gain new insights.

The past decade has seen growing interest and investment in TD education and research centers. In October 2004 seven academic institutions were awarded grants totaling $14.5 million by the National Cancer Institute (NCI) and the National Institute on Drug Abuse (NIDA) to create the TD Tobacco Use Research Centers. Together NCI and NIDA spent about $70 million for the effort over five years \[17, 18\]. In July 2011 funding was announced for new TD Research on Energetics and Cancer Centers (TREC initiative) for four research centers and one coordination center in a $45 million effort over five years \[19\]. Recently, many new announcements were made to establish TD collaborative research centers \[20, 21, 22\]. Doctoral students at the Claremont Graduate University must take a TD course \[23\].

Transdisciplinary Research Process

The goal of this paper is to integrate TD skills and learning into undergraduate STEM research education to provide students with an opportunity to utilize their scientific knowledge while working on a wide range of topics (e.g. challenging technical, medical, social, and cultural
issues). Figure 1 [25] shows the proposed TD research process model, which is conceptualized in three phases: 1) collaboratively defining the research problem objective(s) and building a collaborative research team; 2) developing collective intelligence and producing transferable new STEM knowledge through collaborative research to solve the societal problem in question; and 3) TD assessment and knowledge integration in engineering.

![Transdisciplinary Research Process Model](image)

**Figure 1. Transdisciplinary Research Process [24]**

**Team Building and Collective Understanding of the Research Problem**

Transdisciplinary-teams can be developed with distributed leadership -- team leadership will change in accordance with the particular expertise required. Most of the time, structuring and understanding of a complex problem may become problematic -- collaborating team members may not even agree on what the problem is and no solution can make everyone happy [25].

**Interactive Management (IM) Workshop**

Assume that there is a complex problem in hand to be structured by engineering undergraduate students. Assume that research sub-project teams of four with specific roles for each sub-project teams are considered. Depending on the assigned task, each sub-project team may have minimum of three and maximum of five students. Using any communication platform, a workshop can be organized where sub-project teams will introduce their project proposals (concepts) about the complex problem being explored. Through dialog, the collective best ideas of sub-project teams will emerge and the incorrect or fuzzy ideas that teams held at the outset will be recognized as incorrect or sharpened to make them useful. Through the Interactive Management (IM) process [26], Ideas with high interaction will be grouped into clusters. Thus, team members can identify and examine cluster interactions internally and interactions between clusters. Clusters will be placed in a sequence by using Interpretive Structural Modeling (ISM) [27].
Through Interactive Management (IM) Workshop sub-project team members will experience the mutual understanding and learning that are an integral part of the TD research process. Outcomes obtained with IM include [26]:

• **Learning.** Students engaged in an IM activity are exposed to a real sharing of ideas and information, and hence are actively learning about the research project at hand.

• **Commitment.** Final modular project is created participatively. Through this kind of approach genuine commitment can be achieved.

• **Documentation.** During the IM process information generated by team members and decisions taken will be recorded and organized, and provide the basis for broader diffusion of the outcomes.

**Development of Collective Intelligence -- Interpretive Structural Modeling**

Interpretive Structural Modeling (ISM), a methodology for dealing with complex issues was proposed by Warfield in 1973. It is a computer-assisted learning process that provides fundamental understanding of how various parameters (elements, variables, system components, etc.) relevant to the complex problem or issue interrelated and thus helps researchers to structure them in a meaningful manner to develop collective intelligence to overcome challenging complex problems.

This interactive learning, information processing, and developing collective intelligence is especially useful for working in a group to develop a map of the complex relationships between various elements involved in a challenging complex issue. The relationship map includes paths of ideas and threads of thought to transform unclear and poorly expressed mental model of an issue into a visible, well defined, and relatively easily solvable model. The fundamental approach of this process is to use academic and non-academic experts’ practical experience and knowledge to decompose a complex issue into smaller sub-issues and build a simpler multilevel structural model.

**Transdisciplinary Assessment and Knowledge Integration**

Transdisciplinary assessment (TA) includes integrating people (social), artefacts (technical), and knowledge (cognitive) associated with different scientific and non-scientific knowledge domains [28] into an appropriate methodology [29]. Societal players who are affected by a problem must be drawn into the research process to effect scientifically valid research (see Figure 1).

Data will be collected using Design Structure Matrix (DSM). Team-based DSM is used for information flow among team members or teams [30]. The following possible ways of information flow will be captured [31]:

• **Level of Detail** – Sparse (Documents, e-mail) to rich (models, face-to-face)

• **Frequency** – Low (batch, on-time) to high (on-line, real)

• **Direction** – One-way to two-way

• **Timing** – Early (preliminary, incomplete, partial) to late (final)

More information on transdisciplinary research process can be found in reference [24].

**Transdisciplinary Core Modules**

Learning modules to facilitate undergraduate students to learn specific subject and difficult concepts proven to be effective [32-33]. A truly integrated approach to preparing students for
transdisciplinary problem-solving must mirror that approach in the education process. The Transdisciplinary modular approach has been developed to be suitable for undergraduate design education. The content of the four core modules is based on engineering principles and includes information and knowledge common to multiple disciplines and appropriate shared concepts and methods. They are designed to enable students to progressively synthesize the modular information and create new knowledge as they solve a given research project. The four synchronized TD core modules will provide the students with a foundation in the TD skills required to identify, frame, and address important practical problems that cut across disciplinary boundaries and are structured so they can be mixed and matched with other courses or to redesign a course. The resulting core modules consist of:

*Transdisciplinarity and Complexity Management (1):* A practical foundation for complexity management (related to human behavior, societal systems, economic systems, and environmental systems) will be presented that enables a system’s complexity to be evaluated against its functions and qualitative factors, such as social mores and human values. The course will cover

- a) definitions and characteristics of complexity;
- b) understanding complexity: thought and behavior;
- c) modeling of complex systems;
- d) tools and methods for managing complex systems;
- e) strategies for reducing social complexity;
- f) complexity and structure;
- g) management of knowledge and integration;
- h) managing complexity through systems design;
- i) Interactive Management.

*Transdisciplinary Design Process & Sustainable Development (2):* Fundamentals of TD design and research processes and applications, TD assessment and methodology development to guide research, policy and action towards sustainability will be covered. Students will learn broad research skills and knowledge in strategies for sustainable integration, sustainable resource use and management, environmental conflict resolution, policy formulation and decision-making. Rural and urban sustainability, ecological sustainability, the interconnectivity of environment, economy and society will also be covered.

*TD Research and Discovery (3):* The focus of this course is to enable the students to work jointly with others across disciplines. This course covers: generic design; idea generation and management; brain-writing pool and idea structuring; tradeoff analysis methodology (TAM); collaborative activities, practice and research ethics; TD research process using a systems approach; impact of social issues on design; the role of experts in TD research processes and TD case studies.

*TD System and Product Development (4):* This module teaches system and product development methods, techniques and tools so that engineers can have a big-picture view of the whole system/product lifecycle and can use systematic approaches to design and develop products and systems. Risk assessment, and how to deal with uncertainties will also be covered.

**TD iTextBooks**

The TD iTextBooks integrate knowledge among 8 identified disciplinary areas (through supplementary modules) to provide necessary content to help students learn the fundamental concepts of design. Supplementary modules are:

1. A Transdisciplinary Framework for Engineering Systems Research and Education based on Design and Process
2. Design for Fatigue
3. Materials for Design
4. Statistical Decisions and Reliability Modeling
5. Prevention through Design and case Studies (PtD)
6. Experimental Design
7. Biomimetic Design
8. Engineering Ethics

Supplementary modules are designed to be stand-alone, and...
instructors will be able to assemble custom and focused content. This focused approach will help students master the most pertinent and applicable subject matter. Although four synchronized TD modules with content are developed, supplementary modules are not synchronized. Students will use them as needed depending on the nature of the design project.

**Transferable New Knowledge Creation and Application**

The content of the TD core modules, based on engineering design principles, will include information and knowledge common to multiple disciplines. Students will progressively synthetize the TD modular information and create new knowledge and ideas to solve a given research project.

*Expected results:* Students will develop TD skills through *modular research* projects, and collaboration with other students and practitioners/domain experts. They will learn, practice, and develop skills such as: *social* (accepting and sharing responsibilities, collaborating, resolving conflict); *thinking* (acquisition of knowledge, application, analysis, synthesis, evaluation, metacognition); *research* (formulating questions, planning, collecting, and interpreting data, presenting research findings); *communication* (listening, speaking, reading, writing, presenting); *TD management* (management of interest, conflicts, and relations; management of communication and information; management of knowledge and integration; management of organization; management of complexity) [34, 35, 36].

**Modular Projects Development**

The transdisciplinary program promotes *project-based learning*. A project-based learning experience may have a great impact on student motivation [36]. Instead of assigning the students a project, the instructors will assign projects to be conceived and developed by student groups to reinforce fundamental concepts and to generate innovating projects. Students will be allowed to (a) develop their own research-based, open-ended modular projects and (b) propose solutions, employing critical and creative thinking skills. By developing and solving modular projects, students can create solutions outside-the-box and develop skills to strengthen the students’ teamwork and leadership abilities.

**Process of Developing Modular Project**

At the beginning of class, randomly selected students will be broken into sub-projects teams to develop their own independent modular project following the TD research process given in Figure 1. Modular projects will be improved as the TD core modules are covered, providing a progressive approach for designing and developing projects and knowledge synthesis which will include promoting the skills of finding and integrating tools and methods from what have traditionally been separate knowledge areas. A sample research project might be to design and develop an ideal self-sustaining rural eco-village system in a multi-project environment (approximately 100 people live in independent 30 homes).

**Suggested Requirements to Complete Modular Research Projects**

Sub-project teams must actively deal with some of the following generic design requirements to complete their independent modular project to achieve their research goal:

1) Relate the modular research project to:

   a) Energy, recycling, human health, security, disasters, economics, management;
   b) Sustainability (addressing environmental, economic, social aspects);
   c) Technological consciousness;
d) Transportation and societal issues; and
e) Diversity.

2) Integrate planning and technical aspects (design, process, and systems) as well as economic, ecological and social goals;
3) Consider functional requirements, ethical, safety, and contemporary issues;
4) Identify and rate potential risks associated with the project; present a coherent strategy for mitigation;
5) Develop visually pleasing website with an economically and functionally innovative solution;
6) Evaluate and report the transdisciplinary attributes given in Table 1; and
7) Complete the sub-modular project proposal.

Table 1. Criteria for Determining Transdisciplinarity

<table>
<thead>
<tr>
<th>Indicators Of TD</th>
<th>Degree of Indication</th>
</tr>
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<tbody>
<tr>
<td>Deeper understanding of the material</td>
<td>Check: midterm and final exams (Individual); modular research projects to what degree and how correctly methods and fundamental concepts are used. (Individual and Team Levels)</td>
</tr>
<tr>
<td>Transdisciplinary skills</td>
<td>Check: problem-solving, conducting research, communication, and self-management skills, self-efficacy, survey of student attitudes and interest [34, 35, 36, 38, 39].</td>
</tr>
<tr>
<td>Knowledge integration</td>
<td>Check: whether content of research outcomes (final integrated modular research projects) reflect knowledge integration; diversity of knowledge sources; knowledge sharing from different sources; # of the integrative steps set out and how well the steps were carried out [40].</td>
</tr>
<tr>
<td>Generation of new knowledge that transcends discipline boundaries</td>
<td>Check: content of the research outcome (final integrated modular research projects); what kind of existing data and information are used to transform them into a new knowledge; knowledge assets such as intellectual capital (frequency count).</td>
</tr>
<tr>
<td>Collaboration and team processes</td>
<td>Check: practice of collaboration of the project teams with different disciplines; transdisciplinary behavioral patterns of project team members; use of external experts [41, 42, 43].</td>
</tr>
<tr>
<td>Innovation</td>
<td>Check: capture of new physical phenomena; adaptation of existing technologies; use of disruptive technology [11, 44].</td>
</tr>
<tr>
<td>Creativity</td>
<td>Check: concepts generated (fluency); diversity of concepts (flexibility); originality of concepts (originality); amount of detail (elaboration); technological creativity (invention); economic creativity (entrepreneurship) [5].</td>
</tr>
<tr>
<td>Management, leadership and networking</td>
<td>Check: how well the organizational structure fosters communication; networking among group members and teams; joint work activities and shared decision making; leadership tasks [43, 45].</td>
</tr>
<tr>
<td>Research and bibliometric indicators</td>
<td>Check: literature search, diversity of the references, content of the research outcome, possible paper publications resulting from project; research benefit to society [41].</td>
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</tbody>
</table>
Transdisciplinarity in Practice: Master of Engineering and Ph. D. Education at Texas Tech University

The foundation of the proposed undergraduate transdisciplinary design course described in this paper is based on extensive work by Dr. Ertas to develop the first and only transdisciplinary engineering advanced degree in the nation at Texas Tech University (TTU). In 1999, Dr. Ertas, created a Master of Engineering distance-learning program in Transdisciplinary Design and Process at TTU for Raytheon Company engineers. This was a technology-driven project-based program which provided independent research opportunities to Raytheon engineers. The program curriculum was updated dynamically to respond to technology change and address the difficult balance between covering leading-edge technical material yet providing enough fundamental knowledge to prepare students for the transitions and innovations that are part of the aerospace industry. The primary objective of this program was to provide the opportunity for practicing engineers to earn advanced degrees while continuing their employment. In this program, the typical number of students ranged from 10 to 14 per class from different disciplines (Mechanical, Electrical, computer engineering, math and science) interested in transformative educational agendas for graduate studies through integrative transdisciplinary courses, lectures, and seminars. The courses were taught via on-site (less than 50%) and distance learning techniques.

In 2006, he has expanded the program to create a Ph.D. track in Transdisciplinary Design, Process, and Systems that is offered by the Mechanical Engineering Department at TTU. To improve the curriculum, Dr. Ertas has organized yearly conferences and workshops on TD education to solicit input from the international TD community and these improvements were incorporated into the MS and Ph.D TD programs.

The data collected for this research includes surveys sent to groups of students who had participated in classes taught by Dr. Ertas, and then gone on to careers in Engineering. The respondents to these surveys did not have to worry about answering the survey questions in a specific way because any grades they received from taking courses with Dr. Ertas would already have been given. Furthermore, these respondents were in an ideal position to reflect on their TD education because, not only had they taken multiple classes using some form of TD methods, but they were now working in the field and had the opportunity to reflect on the ways that their education had benefitted them—or not—in their work environments. Respondents were immune to perception bias, and also had the benefit of hindsight when responding to the survey questions. On November 15, 2013, survey questions were developed and sent out to 37 Raytheon engineers for the evaluation of ME, Transdisciplinary Ph.D. program on Design, Process, and Systems in conjunction with the Raytheon Company in Dallas, Texas. The survey questions were divided into three groups: implementation, project related, and curriculum and program related.

Questions related to Implementation
1. How this program affected your job performance? Please rank from 1 (low) to 5 (high).
2. How much you are using the knowledge you learned from this program for the work related projects? Please rank from 1 (low) to 5 (high).
3. How strongly you recommend this program to others? Please rank from 1 (low) to 5 (high).

Questions related to Projects
4. Working on collaborative team projects allowed me to build confidence in problem solving. Please rank from 1 (low) to 5 (high).

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5. Evaluate student interaction, communication, and collaboration for the team project. Please rank from 1 (low) to 5 (high).
6. Evaluate the value of individual project. Please rank from 1 (low) to 5 (high).

Questions related to Curriculum and Program

7. How would you rank the non-traditional curriculum of this transdisciplinary Ph.D. program? Please rank from 1 (low) to 5 (high).
8. Is this a technology driven project based program? Please rank from 1 (low) to 5 (high).
9. How would you rank the overall quality of this transdisciplinary Ph.D. program? Please rank from 1 (low) to 5 (high).
10. How would you rank your communication and discussions with the instructors teaching the TD courses? Please rank from 1 (low) to 5 (high).
11. Your general comment about the Transdisciplinary Ph.D. Program.

Response rate for the survey was better than expected -- 30 responses were received. Some Examples Response to Q#11 are:

- The Transdisciplinary Ph.D. program was well organized around the areas of technical matter that develops the process and thinking required to focus on research driven by applications. I found myself jumping into the guts of technical aspects of engineering and the science behind it such that the systems that we studied and did research on proved to be helping me widen my horizon and helped me identify and break down problems into smaller parts to come up solutions.
- The TD Ph.D. Program is tailored to the needs of working engineers looking to continue their education. The topic of transdisciplinarity and associated courses provide a bridge between traditional disciplines and allows the students to better integrate knowledge from multiple functions in their academic and professional work.
- I found the Texas Tech Ph.D. program demanding and it covered the intense interactive teamwork required to develop top professional engineering leaders in an ever changing technology environment. The key to how far a Ph.D. graduate well excel is determined by the choice of dissertation topics and how active he becomes in adding to the body of knowledge within Transdisciplinary Engineering.

Table 2 Group I Results -- Implementation Related

<table>
<thead>
<tr>
<th></th>
<th>Q#1</th>
<th>Q#2</th>
<th>Q#3</th>
</tr>
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<tbody>
<tr>
<td>Excellent</td>
<td>14(46.6%)</td>
<td>15(50%)</td>
<td>27(90%)</td>
</tr>
<tr>
<td>Good</td>
<td>13(43.3%)</td>
<td>6(20%)</td>
<td>2(6.67%)</td>
</tr>
<tr>
<td>Average</td>
<td>3(10%)</td>
<td>9(30%)</td>
<td>1(3.33%)</td>
</tr>
<tr>
<td>Poor</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Very Poor</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>30(100%)</td>
<td>30(100%)</td>
<td>30(100%)</td>
</tr>
<tr>
<td>Mean</td>
<td>4.3667</td>
<td>4.2000</td>
<td>4.8667</td>
</tr>
<tr>
<td>Standard Dev.</td>
<td>0.6687</td>
<td>0.8867</td>
<td>0.4342</td>
</tr>
</tbody>
</table>

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Tables 2, 3, and 4 show the results of the survey in three groups.

As shown in Table 2, approximately 90 percent of the respondents (46.6% “Excellent” and 43.3% “Good”) perceived that this program affected their job performance (Q1), and 70 percent (50% “Excellent” and 20 percent “Good”) agreed that the knowledge they learned from this program they use for the work related projects (Q2). Almost 97% of the respondents strongly recommend this program to others. That is why 43 Raytheon engineers enrolled in Transdisciplinary Ph.D. program in four years.

The questionnaire for group II consisted of three questions to evaluate student interaction, communication, and collaboration in individual and team projects. As shown in Table 3, the respondents’ overall team project experience (Q4) was positive with 86.67 percent choosing either “excellent” or “good” indicating that working on collaborative team projects allowed students to build confidence in problem solving. Furthermore, almost 90% of students had a very
positive experience collaborating as a team; this is an important statistic given the anxiety that many students feel over working on a team for a grade. Also important to note is that students had the lowest level of satisfaction with the individual project—about 76% compared to the 90% for the group work. This suggests that creating more group work opportunities is important.

The questionnaire for group-III asked questions related to curriculum and the overall program. As indicated in Table 4, more than 96 percent of the respondents answered that they were very happy with the non-traditional curriculum (Q7) and quality (Q9) of the T D Ph.D. program. However, only about 76% of students believed this to be a technology-driven program. While many students felt comfortable discussing concerns with instructors (about 93%), perhaps more collaboration between students and instructors could have yielded either slight changes in the curriculum or more discussion over what ‘counts’ as a technology-driven curriculum.

Realistically, we can assume that overall; the TD Ph.D. program received positive evaluations. However, we have identified some problems through questions 2, 6, and 8 for corrective action. Progress toward the identified problems for improvement will be discussed and evidence of progress will be collected by the director of the program starting fall semester of 2015 with the new group of Ph.D. students.

**Discussions**

Although the past decade has seen growing interest and investment in TD graduate education, undergraduate education remains predominantly dependent upon narrow, disciplinary foci. To prepare students to become well-trained professionals, engineering programs must start integrating TD courses into the undergraduate curriculum. Although researchers have become accustomed to working across disciplinary boundaries, the undergraduate classes offered by many universities have been the same for decades. Undergraduate students should master TD competencies before they go on to graduate studies or employment.

In order to meet new challenges in the 21st century, universities around the world are seeking to broaden their science and engineering education systems. Creativity and innovation become increasingly important in higher education policy. Evidence reveals that “the emergence of new engineering disciplines has historically matched the pace of increases in technological innovations, with both the number of disciplines and technological innovation doubling at a rate of between 31 and 35 years” [46]. Recently, creativity models in education have been implemented and used by educators to seek to drive greater innovation and technological advancements. For example, TRIZ-based Creativity model was used to advance undergraduates’ creativity and innovation by several authors [47, 48]

Transdisciplinary can help in making creativity more evident in the teaching and research activities of universities [49]. The growing understanding of the importance of technological innovation to economic competitiveness is challenging a new urgency for engineering education and research at the extremely difficult technical, medical, social, and cultural problems. Lack of knowledge base to solve these problems is becoming more and more predominant. Therefore, engineering education must produce highly qualified, well-trained engineers who can interface with other sectors of society to address complex problems require many activities which cross discipline boundaries.
There is a need for Transdisciplinary Design Culture (TD - DC) in higher education which can be built on the existing foundation that is provided by math, art, science, and humanities. As shown in Figure 2, these four TD core courses should be in perfect harmony – they should be interconnected for the mutual exchange of knowledge. TD core courses are designed in a way that the specific subjects within and among the TD core courses can be easily synchronized and complement each other. Then, we can assume that interconnectivity is exist and TD core courses are connected without boundaries within the TD – DC domain. This process provides a knowledge capability that is greater than the sum of the contributing core courses [50].

![Figure 2: Domain of transdisciplinary design culture](image)

College textbook costs have increased four times the inflation rate in the past decade. While a college education is essential for obtaining a job in today's world, college is pricey and impractical for many families. Upon entering college, students and their parents are unexpectedly faced with the high price of textbooks. College textbooks can add thousands in cost to a student's education expenses. This is a tremendous financial burden for many students and their families and has a negative impact on federal and state government spending as financial aid providers [51].

Government studies also report a substantial increase in textbook costs. A congressional advisory committee held several public hearings to discuss the role of the federal government and state governments in aiding universities to keep the cost of textbooks down. “In the survey, released by the U.S. Public Interest Research Group, a nonprofit consumer-advocacy organization, 7 in 10 students have skipped buying a required textbook because of its high cost. Students know that textbooks are necessary to their education but have been pushed to the breaking point by skyrocketing costs, said Rich Williams, Higher Education Advocate for U.S.
Public Interest Research Group (PIRG). The alarming result of the study underscores the urgent need for affordable solutions” [52]. The survey polled 1,905 undergraduates from 13 campuses spring of 2011. The major finding was that 70% of respondents forewent buying at least one assigned textbook due to cost. While a number of these students reported sharing or borrowing instead, 78% still believed that they would usually do worse in class without their own copy of the required textbook [51].

The TD Core Modules developed for the advanced programs are now modified for the undergraduate-level by Dr. Ertas. He has produced and will offer free, new undergraduate TD educational materials in the form of Internet Text Book compose of twelve modules (iTextBook) to approximately 70,000 undergraduate students including senior-level engineering students, as well as students from other scientific disciplines. The modules will reside on the ATLAS Digital Library website (www.theatlas.org) which is freely and publicly accessible. Founded in 2000, TheATLAS is a Texas non-profit organization provides free educational materials (books, journal articles, modules, TD tools). The transdisciplinary itBooks process will provide the following benefits:

- Integrating knowledge from one transdisciplinary area into another;
- Creating TD educational knowledge diffused in the modules, hence, graduating TD competent students;
- Aligning module integration with the skills as well as the content of the curriculum;
- Providing accurate content to help students learn the fundamental concepts rather than memorizing the content;
- Including only necessary materials in the module; and
- Selecting modules from a module-pool and integrating them to generate a custom textbook for the specific course that the professor teaches.

Conclusions

This paper examined the transdisciplinary research approach to engineering education and assessed the students’ perceptions of transdisciplinary Ph.D. learning. Further research needs to be done to assess the viability of using TD methods in other programs. It is our belief that transdisciplinary methods could be used effectively at the undergraduate level. Learning modules and delivery methods are designed to enable students to progressively synthesize information and create new knowledge as they solve a given research project; and this pedagogical strategy works well for students of all ages. Thus, more work needs to be done to create and test transdisciplinary programs for undergraduate students. This proposal of creating transdisciplinary courses for undergraduate students will be undertaken as part of a larger project at Texas Tech University. New transdisciplinary courses will be implemented in fall of 2015 in Mechanical Engineering at Texas Tech University as part of a pilot study that aims to rework senior design courses.

The proliferation of complexity in scientific and societal endeavors calls for continual accommodation on the part of those addressing the issues and on the part of educators as well. TD skills will provide the foundation to help prepare students for the challenges, challenges that are presently unforeseen. The ability to analyze and synthesize information, problem-solve head
across disciplines and function in transdisciplinary teams are adaptive skills that will aid in meeting those challenges.

Whether we are prepared for it or not, the future will be here. It is our responsibility as educators to do all we can to enable our students to be successful in their careers and in their efforts to address the unknown problems of tomorrow. Our task is to engage in quantitative as well as qualitative research on possible best practices for education and engineering. We offer TD as a focus of such research and practice.

References


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