International Journal of Engineering Education Vol. 36, No. 6, pp. 1976–1987, 2020
Printed in Great Britain

0949-149X/91 $3.00+0.00

The Impact of Transdisciplinarity on Solving Complex Engineering Problems in an Ethnically Diverse Classroom*

UTKU GULBULAK[1], ATILA ERTAS[1,**] and MCKENZIE CORDELL[2]
[1] Department of Mechanical Engineering, Texas Tech University, Lubbock, TX 79409, USA.
[2] Department of Psychology, Texas Tech University, Lubbock, TX 79409, USA.

This paper studies a transdisciplinary (TD) research approach to undergraduate engineering education to examine alternative learning and consequently, to improve STEM learning outcomes. A paradigm shift in engineering education is required in response to job market uncertainties to mitigate unemployment and prepare students to tackle problems requiring TD knowledge, methods, tools, skills, and expertise from different disciplines and forming novel frameworks to catalyze scientific discoveries and innovations. The expected results of TD research and education are an emphasis on teamwork; collaboration; bringing together diverse science and engineering disciplines; developing and sharing concepts, methodologies, and tools; to solve complex scientific and engineering problems.

The objective of this study is twofold, first to assess the impact of the TD pedagogical approach on the learning outcomes of the ethnic minority students, second to implement and practice Collective Intelligence Management Workshop (CIMW) supported by Transdisciplinary Design Studio (TD^{2}S) for Collaborative Research and Education (CORE).

Keywords: transdiscipline; engineering education; complex problems; transdisciplinary research approach; ethnic diversity

1. Introduction

Rapid technological change and convergence in the globally competitive economy are causing current and future upheaval in job markets. Individuals may have to change career paths more than one time in their lifetime. However, a fast transition is not practically possible [1]. From an engineering standpoint, companies from various industries outsourced engineering-related tasks to international entities [2]. To be competitive in professional life, the undergraduate engineering students will need to have a novel set of skills centered around creativity, innovation, and system integration [3, 4].

Due to the increasing understanding of the importance of technological innovation for economic competitiveness, new pressures now challenge engineering education and research with extremely difficult technical, medical, social, and cultural problems [5]. Unfortunately, the inadequate knowledge base to solve these problems is becoming more and more evident. As a result, engineering education should encourage the production of future engineers who are not bound to one discipline but be able to tackle complex problems using cross-discipline knowledge [6]. Transdisciplinary (TD) methods offer an approach that synthesizes methodologies from multiple fields and a broad and integrative viewpoint. This new approach to creating communities of learners and knowledge creators that work across disciplines is integral to addressing the challenges. The use of TD education approaches is timely since TD methods and pedagogical strategies support the creation of creative, engaged, dynamic, and innovative engineers by cultivating multidimensional learning experience with teaching and research activities at the universities [7–9]. The implementation of TD approaches in undergraduate education prepares future engineers to tackle complex challenges by encompassing all types of knowledge about an idea, issue, or subject through TD thinking [10–14]. From the onset, transdisciplinarity practice has been considered a crucial factor for graduating engineering students' success, for the following reasons:

Students learn how to identify, decompose, and solve complex problems.

- Students learn how to consider the impact of engineering solutions in global, economic, environmental, and societal issues.
- Students learn how to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment to meet objectives.
- Students learn how to create and apply new knowledge for the solution of unstructured problems that benefit society.

The above students' learning experiences are representative of four out of seven ABET 2020

** Corresponding author: Atila Ertas, Department of Mechanical Engineering Texas Tech University, 7th, and Boston, Lubbock, TX 79409, USA. E-mail: atila.ertas@ttu.edu

* Accepted 11 June 2020.

Criterion 3, student outcomes [15]. This study presents TD research approach to undergraduate engineering education in an effort to examine alternative learning and consequently, to improve STEM learning outcomes.

2. Transdisciplinarity in Practice at Texas Tech University

2.1 Initiation of Transdisciplinary Senior Design Course

The TD research approach was implemented in a senior engineering design course in Fall 2015 at Texas Tech University. Senior mechanical engineering students were introduced to TD training. With the focus on complex problem-solving, the course plan was designed to cover complexity management and decision making, TD design process and sustainable development, TD discovery and innovation, TD system and product development. The course design was explained in detail in our previous works [6, 16]. Pre- and post-survey were conducted to investigate the effectiveness of the TD strategy and how the TD knowledge was used to address complex problems [16].

2.2 Fall 2016 Section and Survey

In Fall 2016, TD senior engineering design course continued, and the same pre- and post-survey was conducted to evaluate how repeatable the results from the 2015 section were under a set of similar conditions. Unlike [16], for Fall 2016, only the experimental section was considered. This section had 20 senior mechanical engineering students. While half the students were identified as white, the other half identified themselves as an ethnic minority. Engineering students are consistently shown to have moderate to high levels of stress, and symptoms of depression and anxiety [17–19]. These factors have correlated with lower performance academic and higher levels of academic difficulty among engineering students [18, 20]. These phenomena are further increased in ethnic minority students [21, 22] in addition to minority students experiencing lower self-efficacy [23]. Previous research has shown that peer interactions and faculty to student interactions, as seen in TD classrooms, result in higher levels of academic success and student retention [24–26]. More specifically, peer support has been seen to reduce anxiety in minority students [22] and faculty integration lead to higher self-efficacy and therefore greater critical thinking and student performance [27]. One of the goals of this study was to assess the impact of the TD pedagogical approach on the learning outcomes of the ethnic minority students. Survey questions were designed to understand if TD research approach would result in better TD problem-solving skills. The survey included four questions, which asked students to rate themselves, and a research question. Fig. A1 shows the pre- and post-survey (see Appendix A).

2.3 Data Analysis

The collected responses were modeled with the location-scale "t" distribution. An additional sample t-test, with a 95% confidence level, showed that GPA did not have a significant difference in GPA averages. Because of the non-responses (no response for post-test) and inconsistencies, three students' survey results were eliminated from the analysis. Fig. 1 shows the pre- and post-survey results of the first four questions. A comparison of pre and post-tests results show that students' TD learning related to four survey questions was improved. For Q1, ". . . ability to trust other members" was rated very high compared with the other three questions. Results of the standard deviations of Q1 and Q3 reveals that students' ability to trust and collaborate across disciplines improved uniformly among the students. Fig. 2 shows the averaged results of the first four questions from pre-and post-survey.

The averaged results of the TD learning were evaluated with confidence interval estimation. The confidence interval estimation was implemented

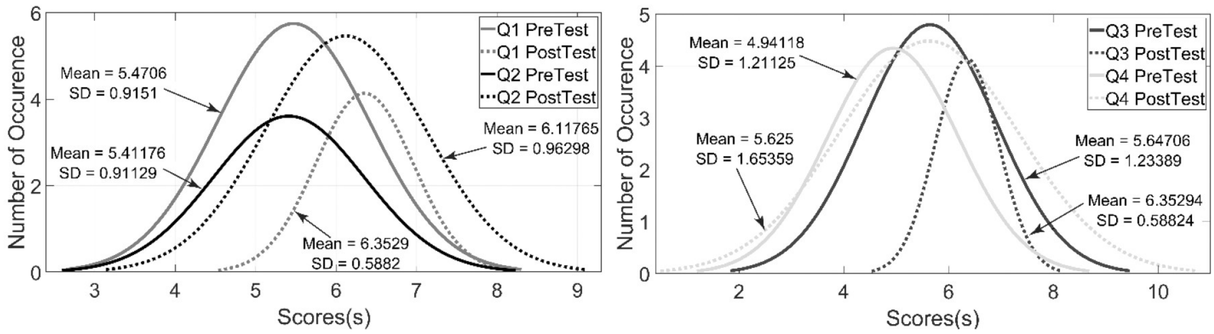

Fig. 1. Measuring TD learning for 4 questions.

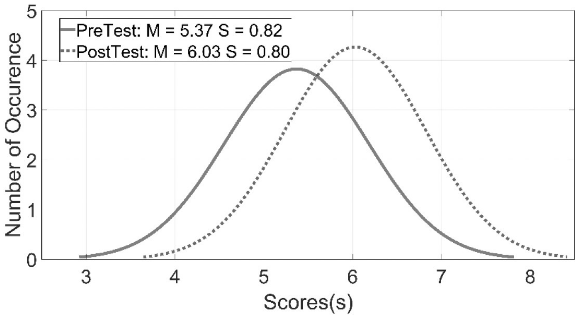

Fig. 2. Measuring TD learning for 4 questions.

with the difference in two means, variance unknown, to observe whether the results from pre- and post-survey were statistically significant [16]. Since the sample size is less than 30 the unknown variance is estimated with "pooled" estimator as follows [28];

$$S_p^2 = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2} \quad (1)$$

A 95 percent two-sided for the difference in means $(\mu_1 - \mu_2)$ was defined as follows:

$$(\bar{x}_1 - \bar{x}_2) - t_{\alpha/2,N} S_p \sqrt{1/n_1 + 1/n_2} \leq (\mu_1 - \mu_2) \leq (\bar{x}_1 - \bar{x}_2) + t_{\alpha/2,N} S_p \sqrt{1/n_1 + 1/n_2} \quad (2)$$

where α equals 0.05 and $N = n_1 + n_2 - 2$. Statistical significance was determined on one condition: If the confidence interval would not include $\mu_1 - \mu_2 = 0$, then the mean difference would be considered significant. This hypothesis was tested through an analysis with equations (1) and (2). Table 1 shows a summary of the calculations of the Fall 2016 section. Additionally, the Fall 2015 results were provided for comparison.

Table 1 shows that for Fall 2016 section $\mu_1 - \mu_2 = 0$ condition was not found in between 0.0941 and 1.2259, therefore the difference between the pre- and post-survey is statistically significant at the 95% confidence interval as the Fall 2015 section. However, since the post-survey standard deviation is higher than the Fall 2015 section, it can be concluded that TD learning of Fall 2016 section students was varied whereas in the Fall 2015 section it was more uniform.

To evaluate individual learning outcomes, during the pre- and post-survey, the collected surveys were numbered. Fig. 3 shows the individual averaged scores from the first 4 questions.

As shown in Fig. 4, Student #8 and Student #9 did not show improvement in TD learning as their pre-survey and post-survey averages were the same. The remaining 15 students in the class showed an increase in TD learning. It is interesting to note that Student #12, identified as an ethnic minority, exhibited a significant increase in TD learning. Additionally, Student #17, identified as white, showed a significant jump in TD learning.

Table 2 shows the breakdown of the average scores from the first four questions for white and ethnic minority students in the Fall 2016 section. For the Q1, the mean scores of the ethnic minority students increased by 1 from pre-survey to post-survey and the mean scores of the white students were increased by 0.8. The Q1 results showed that ethnic minority students improved their ability to trust other members of the class more than white students. It should be noted that while the standard deviation from white students significantly

Table 1. Summary of calculations from sections Fall 2016 and Fall 2015

Sections	S_p	$\nu(df)$	$\leq \mu_1 - \mu_2 \leq$	$\bar{X}_{pre}$	$\bar{X}_{post}$	S_{pre}	S_{post}
2015 Section	0.616	17	$-0.877 \leq \mu_1 - \mu_2 \leq -0.593$	5.294	6.0294	0.6745	0.5512
2016 Section	0.810	17	$0.0941 \leq \mu_1 - \mu_2 \leq 1.2259$	5.370	6.0300	0.8200	0.8000

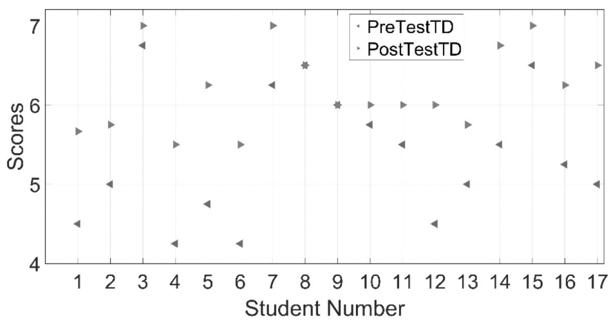

Fig. 3. The individual averaged scores from the Fall 2016 section. Each student was represented with a number.

Table 2. Pre- and post-survey results by ethnicity.

		Q1		Q2		Q3		Q4		Total	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Pre-Survey	**White**	5.60	1.07	5.00	0.67	5.20	1.40	4.50	1.08	5.08	1.06
	Ethnic Minority	5.29	0.76	6.00	1.00	6.29	0.76	5.57	1.27	5.79	0.95
Post-Survey	**White**	6.40	0.52	6.40	0.52	6.40	0.52	5.30	2.00	6.13	0.89
	Ethnic Minority	6.29	0.76	5.71	1.38	6.43	0.79	5.43	2.51	5.97	1.36

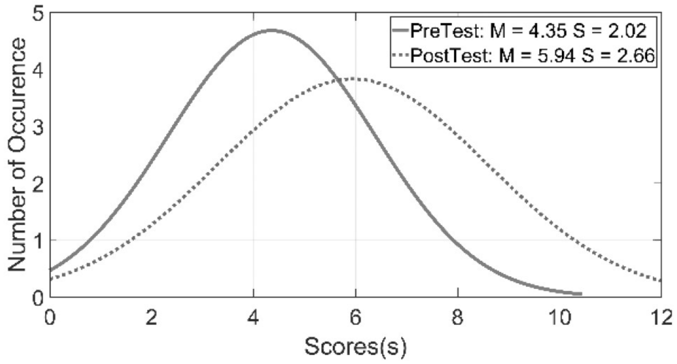

Fig. 4. The results of Golden Eagles and Prairie Chickens research question.

decreased, it remained the same for the ethnic minority students. For the Q2, the calculated mean values decreased for ethnic minority students – their ability to use "outside" knowledge from experts to solve complex problems decreased. This stood as a contradiction with the TD research approach since it was expected that the TD methods would encourage obtaining outside information. It is interesting to note that the standard deviation increased to 1.38. It can be deduced that the ethnic minority students do not feel as comfortable as white students to reach out to field experts to obtain "outside" knowledge. A similar increase in standard deviations was also observed in Q4 for both white and ethnic minority students.

This research also investigated the students' abilities to solve complex problems. Q5 was introduced to assess this. It was expected from students to demonstrate their understanding of the real-world problems and the need for knowledge and skills from a variety of disciplines. A scoring rubric was implemented [16, 29]. The scoring rubric evaluated 3 different skills. The skills were understanding the problem, making a plan, and proposing a solution. Each skill was scored with 4 different score levels. Each scoring category described the characteristics of a response that would receive the respective score. The scoring rubric was developed by identifying the needed qualities to demonstrate skillful performance [30].

The pre- and post-surveys were scored by three people and the averaged scores were given in Fig. 4. To observe the statistical significance between the means, μ_1 and μ_2, the pooled estimator was computed. The pooled estimator found to be 2.345. The two-sided confidence interval for the difference in means, $\mu_1 - \mu_2$ was: $-0.0483 \leq \mu_1 - \mu_2 \leq 3.2283$. Since the condition of $\mu_1 - \mu_2 = 0$ could be found in that interval, the difference the pre- and post-survey was not statistically significant. Although there was no significant difference between the results of pre- and post-surveys, change in mean and standard deviation results showed considerable shift. An increase in mean (approximately 26%) reveals that students' TD research understanding improved. On the other hand, the increase in standard deviation showed that this understanding is not uniform but varied–all the students' understanding is not close to mean value–but spread out. Like the Fall 2015 section [16], it was expected to observe no statistical difference in Fall 2016 as well. The intriguing aspect of the Q5 was being a social research problem intertwined with more than one dynamic. Since the Golden Eagles and Prairie Chickens question was a complex social problem, it can be considered as a top tier TD research problem. The students in the Fall 2016 section was introduced to team building dynamics and recognize the complexity of a problem. In addition, they were able to break a complex problem into understandable and meaningful pieces through TD tools. Even though they understood the TD research process completely, they did not fully practice the TD research process.

3. Group Collaboration and Collective Intelligence

Aukrust [31] stated that the creation of a learning environment, which involves collaboration with the students and students challenging one another, promotes learning experiences as the act of learning is initiated when individuals are engaged with each other and their surroundings. Students learn more effectively in classes where they can interact with their peers and listen to different points of view and experiences [32]. The concept of Interactive Management (IM) was developed at the University of Virginia in 1980. Since then, the practice of IM has spread too many places, and many applications have been carried out. IM is a system of management developed specifically to apply management of complexity to cope with issues whose scope is beyond that of the normal type of problem that organizations can readily solve [33]. When computer scientist Tim Berners-Lee invented the World Wide Web in 1989, creativity, collaboration, and innovation exploded that we have never seen before. Online information-sharing in real time between researchers made IMW more effective. IMW has been renamed as Collective Intelligence Management Workshop (CIMW) to be the building block of the Transdisciplinary Design Process [28].

3.1 Practicing Collective Intelligence Management Workshop

The Fall 2015 Section was the first time we have practiced Collective Intelligence Management Workshop (CIMW) with the new Transdisciplinary course that we have developed. Four foundational core modules were covered in this TD course to train students for a variety of subjects to support complex problem solving. The content of the TD core modules, based on engineering design principles, included knowledge common to engineering disciplines and provided the students with a foundation in the TD talent and skills required to address complex issues that cut across disciplinary boundaries. Four core modules were [16]: (1) Complexity Management & Decision Making, (2) Transdisciplinary Design Process & Sustainable Development, (3) Transdisciplinary Discovery and Innovation, and (4) Transdisciplinary System and Product Development.

As shown in Fig. 5, CIMW has three phases [33]: (a) the planning phase to identify the people, information, and facilities need; (b) the workshop phase involves bringing a selective group of people together from expert domains who have knowledge about the issue in hand to create substantial communication among the group members to identify main factors affecting complexity of an issue. Then, working group continues to debate for establishing contextual relationship among the factors to develop structural self-integration matrix required fundamental knowledge to decompose the complex problem into understandable and meaningful pieces; and (c) the follow-up phase include iteration of the problem solution and its implementation.

The outcomes obtained through this CIMW process include [33]:

Learning. Students who participated in the CIMW process are exposed to a real sharing of ideas and information, and therefore are actively learning about the design research project at hand.

Commitment. The final design project concept is created through the collaboration of students and instructors. Through this kind of approach, true commitment can be achieved.

Documentation. During the CIMW process, information and decisions generated by research team members were documented and organized – provide the basis for broader dissemination of the outcomes.

To support CIMW, we have also developed a Transdisciplinary Design Studio (TD^{2}S) for Collaborative Research and Education (CORE) and integrated with the new TD course. The Transdisciplinary Design Studio is composed of three elements [16]:

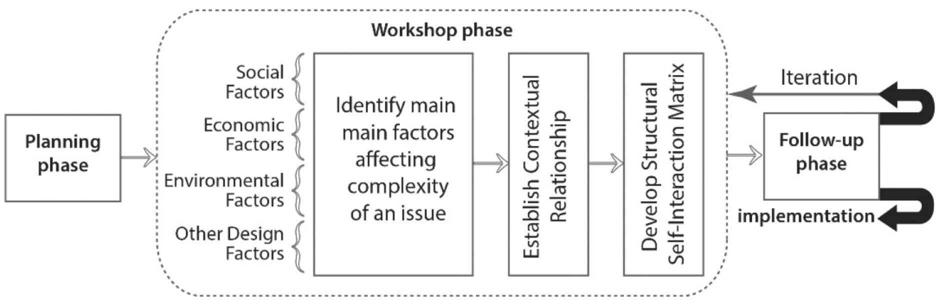

Fig. 5. Three phases of CIMW.

Technology Embedded Learning (TEL): connected our TD classroom through social media and video platforms with others.
Domain Experts: with TEL platform, student groups will be able to contact domain experts to create collective impact.
Creativity Tools & Techniques: using TD methods and tools, students will learn how to become more creative.

CIMW was performed in Fall 2015 under the guidance of instructor of the course as CIMW facilitator and trained Ph.D. student who is familiar with the CIMW process. The follow-up phase of this workshop was the implementation of the project during the 2015 Spring semester. In a traditional senior engineering capstone design course, design teams, build and test solutions to manageable real-world problems – whole class would be divided into design groups and each group would work on their individual design projects. At the beginning of the new TD design class, 17 students were divided into 4 preliminary teams to develop their own independent design project idea – members of the team had no previous working experience with team members other than taking classes together in previous semesters. CIMW was conducted through multimedia conferencing, electronic mails, discussion boards and interactive chatting as a communication platform (Blackboard Collaborate recordings). During the CIMW, preliminary groups presented their proposals about the project they would like to work on. Preliminary teams generated following 4 different design project concepts: (1) Texas Eco Railways (High-Speed Train System Design), (2) Tidal Power, (3) Water Crisis, (4) Lubbock Weather. The advantages and disadvantages of each design project concept were discussed, voted, and ranked. Finally, "High-Speed Train System Design" was selected as the final design project concept. The selected concept was deconstructed in sub-systems. These sub-systems were used to create "Expertise Groups". There were 4 main sub-systems [16]: (1) Economic Modelling, (2) Mechanical Design, (3) Electrical Design, and (4) Social Issues. Sub-project teams were rearranged after the final project decision and deconstruction according to the students' interests and experiences.

3.1.1 Case Study: QFD Development through Collective Intelligence

In High-Speed Train System Design, Quality Function Deployment (QFD) tool is used to help capture basic knowledge (voice of the customer, VOC) from the customers and make it specific (customer needs, CN). VOC is a raw, unfiltered source of input obtained from many customers' narratives. The interpretation into needs can be done by use of VOC as well as other narratives such as focus groups, surveys, experts' opinion, literature search, etc. – QFD team should genuinely investigate what is truly needed.

Instead of implementing QFD by the entire class, 17 students, first, each sub-system expertise group developed their own QFD by using survey, experts' opinion, and extensive literature search to establish customer needs. Conducting a survey was the most feasible and fast way to reach out to the customer and extract their experiences, habits from existing transportation and industrial vehicles, and expectations from a prospective system design for transportation. The survey helped the design teams to figure out their positions in the existing respective competitive markets how they stand comparison in terms of meeting target customer's needs. After the customer's needs have been identified by each design team, the team converts them to engineering requirements for the system design. Then, these engineering requirements become parts of the design requirements. Figs. A2, A3, A4, and A5, in Appendix A, show QFD developed by each subsystem expertise group. As seen from the figures, decisions made for QFD development by each group are quite different from each other. Note that at this stage of the process, student research teams did not use the CIMW facilitator – each group used discussion leader rather than CIMW facilitator.

CIMW with Facilitation

Brainstorming, debating, interacting collection of difficulties related to the success of high-quality results through CIMW was guided by the facilitator. To properly determine the customer opinions, all the information obtained [survey results, experts' (five practicing engineers from different companies) opinion, literature search, student brainstorming (17 undergraduate students and two Ph.D. students)] by the research groups were put together and clustered using the KJ diagram [34]. Customer requirements were identified through formal discussion (debating). Then, filtered customer requirements were displayed in the QFD. The collective result is shown in Fig. A6, in Appendix A. It is interesting to see that how the relationship pattern of this figure is different than the QFD results obtained by the sub-research groups (see Figs. A2, A3, A4, and A5 in Appendix A). The CIMW process facilitated the development and understanding of relationships while providing high-quality results for organizing information relevant to the High-Speed Train System Design.

4. Conclusions and Recommendations for Future Research

This paper presented the implementation of the TD research approach in higher education. The TD research approach was included in the senior engineering design course. The motivation behind this implementation was to change engineering education to train future engineers for real-world complex problems. The TD research approach was first implemented in Fall 2015 at Texas Tech University and continued through the 2016 academic year. In Fall 2016, students have introduced concepts of team building and understanding of the complexity of a problem. The 2016 TD design class students' abilities to solve complex problems were tested. They learned and practiced how to recognize complex problems. They also became skilled at TD tools to decompose complex problems to a meaningful and understandable simple levels. In addition, a case study of the Collective Intelligence Management Workshop (CIMW) was presented. Quality Function Deployment was used as a TD tool in CIMW. It was implemented in the High-Speed Train System Design in the Fall 2015 section. Initial QFDs were prepared by sub-research groups. 4 different QFD were developed. Through discussion led by the CIMW facilitator, customer and engineering requirements of High-Speed Train System Design were determined. Within the limitations of this study, the following conclusions were drawn:

1. The relationship pattern of QFD developed through collective intelligence is significantly different than results obtained by the sub-research groups.
2. TD learning of Fall 2016 section students was varied whereas in the Fall 2015 section it was more uniform.
3. The majority of the students in Fall 2016 class showed an increase in TD learning. Moreover, one student identified as an ethnic minority, exhibited a significant increase in TD learning.
4. The ethnic minority students (Fall 2016 section) did not feel as comfortable as the white students to reach out to field experts to obtain "outside" knowledge.

Implementation of TD research process not only encourages learning outcomes but also provides students with a set of skills needed for complex engineering problems of the 21st century.

Extraneous factors such as stress and psychological symptoms may also impact engineering students' success in the classroom. Continuing to encourage peer support and faculty integration can alleviate stress and anxiety, particularly in ethnic minority students [21, 27]. Future research may benefit from gathering baseline and end post-class data on psychological factors such as stress for the ability to assess as confounding variables or monitor pre- and post-class. The limitation of this research point towards topic to be addressed in the future.

References

1. B. Nicolescu, The Need for Transdisciplinarity in Higher Education in a Globalized World, *Transdisciplinary Journal of Engineering & Science*, **3**, pp. 11–18, 2012.
2. P. Engardio and B. Einhorn, Outsourcing Innovation, *Business Week*, Mar. 21, 2005.
3. C. Moorman, Organizational Market Information Processes: Cultural Antecedents and New Product Outcomes, *Journal of Marketing Research*, **32**(3), 1995.
4. National Academy of Engineering, Greatest Engineering Achievements of the 20th Century, 2007.
5. National Academy of Engineering, NAE Grand Challenges for Engineering, http://www.engineering challenges.org/, accessed: Sept. 7, 2012.
6. A. Ertas, K. M. Frias, H. Greenhalgh-Spencer and S. M. Back, A Transdisciplinary Research Approach to Engineering Education, *Proceedings of the 2015 ASEE Gulf Southwest Annual Conference*, San Antonio, TX, March 25–27, pp. 1–17, 2015.
7. E. McWilliam, G. G. Hearn and B. B. Haseman, Transdisciplinarity for Creative Futures: What Barriers and Opportunities?, *Innovation and Education and Teaching International*, **45**(3), pp. 247–253, 2008.
8. D. Adame, From a Disciplinary to a Transdisciplinary Vision of the University: A Space of Knowledge, Culture, Art, Spirituality, and Life, *Transdisciplinary Journal of Engineering & Science*, **2**, pp. 33–39, 2011.
9. A. Sharunova, M. Butt, M. Kowalski, P. P. Lemgruber, J. Sousa, J. P. Carey and A. J. Qureshi, Looking at Transdisciplinary Engineering Design Education Through Bloom's Taxonomy, *International Journal of Engineering Education*, **35**(2), pp. 585–597, 2019.
10. A. Ertas, T. T. Maxwell, M. M. Tanik and V. Rainey, Transformation of Higher Education: The Transdisciplinary Approach in Engineering, *IEEE Transactions on Education*, **46**(1), pp. 289–295, 2003.
11. J. S. Derry and G. Fischer, Transdisciplinary Graduate Education, 2006. Retrieved from: Report, http://l3d.cs.colorado.edu/gerhard/papers/ transdisciplinary-sharon.pdf.
12. C. M. Gray and T. M. Fernandez, When World(view)s Collide: Contested Epistemologies and Ontologies in Transdisciplinary Education, *International Journal of Engineering Education*, **34**(2), pp. 574–589, 2018.
13. A. Ertas, K. M. Frias, D. Tate and S. M. Back, Shifting Engineering Education from Disciplinary to Transdisciplinary Practice, *International Journal of Engineering Education*, **31**(1), pp. 94–105, 2015.

14. A. Ertas, J. Rohman, P. Chillakanti and T. B. Baturalp, Transdisciplinary Collaboration as a Vehicle for Collective Intelligence: A Case Study of Engineering Design Education, *International Journal of Engineering Education*, **31**(6), pp. 1526–1536, 2015.
15. Criteria for Accrediting Engineering Technology Programs, 2019–2020, Criterion 3, https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-technology-programs-2019-2020/#GC3, Accessed 23 January 2020.
16. A. Ertas, H. Greenhalgh-Spencer, U. Gulbulak, T. B. Baturalp and K. Frias, Transdisciplinary Collaborative Research Exploration for Undergraduate Engineering Students, *International journal of Engineering Education*, **33**(4), pp. 1242–1256, 2017.
17. S. Chenganakkattil, K. Jibinbabu and S. Hyder, Comparison of Psychological Stress, Depression and Anxiety Among Medical and Engineering Students, *International Journal of Research in Medical Sciences*, **5**(4), pp. 1213–1216, 2017.
18. N. Talib and M. Zia-ur-Rehman, Academic Performance and Perceived Stress Among University Students, *Educational Research and Reviews*, **7**(5), p. 127, 2012.
19. S. Usha and D. Solomon, Level of Depression, Anxiety and Stress Among Final Year Engineering Students in a Private Sector, *Research on Humanities and Social Sciences*, **7**(17), pp. 17–20, 2017.
20. A. Ali, M. H. Rao, S. Ali, T. Ahmed, M. Safi, A. Malik and B. Husan, Prevalence of Anxiety and Depression and Their Associated Risk Factors Among Engineering Students in Karachi, Pakistan, *International Journal of Emerging Technology and Advanced Engineering*, **4**(9), pp. 52–55, 2014.
21. C. Arbona, and C. Jimenez, Minority Stress, Ethnic Identity, and Depression Among Latino/a College Students, *Journal of Counseling Psychology*, **61**(1), p. 162, 2014.
22. L. J. Crockett, M. I. Iturbide, R. A. Torres Stone, M. McGinley, M. Raffaelli and G. Carlo, Acculturative Stress, Social Support, and Coping: Relations to Psychological Adjustment Among Mexican American College Students, *Cultural Diversity and Ethnic Minority Psychology*, **13**(4), p. 347, 2007.
23. G. Hackett, N. E. Betz, J. M. Casas and I. A. Rocha-Singh, Gender, Ethnicity, and Social Cognitive Factors Predicting the Academic Achievement of Students in Engineering, *Journal of Counseling Psychology*, **39**(4), p. 527, 1992.
24. L. N. Fleming, K. C. Smith, D. G. Williams and L. B. Bliss, Engineering Identity of Black and Hispanic Undergraduates: The Impact of Minority Serving Institutions, *Proceedings of the 2013 ASEE Annual Conference & Exposition*, Atlanta, GA, June 23–26, pp. 23.510.1 – 23.510.18, 2013.
25. G. Lichtenstein, H. L. Chen, K. A. Smith and T. A. Maldonado, Retention and Persistence of Women and Minorities Along the Engineering Pathway in the United States, *Cambridge Handbook of Engineering Education Research*, Cambridge University Press, Cambridge, pp. 311–334, 2014.
26. T. Saenz, G. A. Marcoulides, E. Junn and R. Young, The Relationship Between College Experience and Academic Performance Among Minority Students, *International Journal of Educational Management*, **13**(4), pp. 199–207, 1999.
27. C. M. Vogt, Faculty as a Critical Juncture in Student Retention and Performance in Engineering Programs, *Journal of Engineering Education*, **97**(1), pp. 27–36, 2008.
28. A. Ertas, *Transdisciplinary Engineering Design Process*, John Wiley & Sons, New Jersey, 2018.
29. K. Montgomery, Classroom rubrics: Systematizing what teachers do naturally, *The Clearing House*, **73**, pp. 324–328, 2000.
30. S. M. Brookhart, The Art and Science of Classroom Assessment: The Missing Part of Pedagogy. ASHE-ERIC Higher Education Report **27**(1), Washington, DC: The George Washington University, Graduate School of Education and Human Development, 1999.
31. V. Aukrust, *Learning and Cognition in Education*, Boston: Academic Press, Amsterdam, 2011.
32. L. B. Gambrell, L. Mandel, E. Morrow and E. P. Michael, *Best practices in literacy instruction*, Guilford Press, New York, 2007.
33. J. N. Warfield and A. R. Cardenas, *A Handbook of Interactive Management*, Iowa State University Press, Ames, 1994.
34. R. Scupin, The KJ Method: A Technique for Analyzing Data Derived from Japanese Ethnology, *Human Organization*, **56**(2), pp. 233–237, 1997.

APPENDIX - A

1. Rate your ability to trust other members of this class.
Low 1 2 3 4 5 6 7 High

2. Rate your ability to use "outside" knowledge from experts and apply it to complex engineering problems.
Low 1 2 3 4 5 6 7 High

3. Rate your ability to collaborate across multiple spheres of knowledge and practices (with people from other disciplines) both within and outside of the field of engineering.
Low 1 2 3 4 5 6 7 High

4. Rate your creativity level in solving problems.
Low 1 2 3 4 5 6 7 High

5. Please read the following paragraph and answer the question to the best of your ability. Please provide as much detail as possible.

Golden Eagles and Prairie Chickens have had declining populations over the last several decades as a result of habitat loss due, in part, to the installments of wind turbines, and wind energy farms. Yet, we also know that wind turbines are a valuable source of clean energy. How would you change things so that wind turbines can still effectively and efficiently be used, but also create ways to protect the natural habitat of animals l ike the Prairie Chickens and Golden Eagles?

Fig. A1. Pre- and post-survey.

Ranking	
Strong Relationship	⊙
Medium Relationship	○
Week Relationship	▲

Engineering Characteristics

Customer Requirements	Efficient Design	Noise Reduction/Dampening	Ergonomically Designed Seats	Maximize cabin volume	AC power for personal devices	High Speed Internet	Provide steady flow of power	Controls system design	Safe data collection system design	Regulations/policies	Appropriate Route Selection	Amount of energy consumption	Mass of air pollutant	Safety plan	Funding	Score
Low cost ticket price	○	○	○	○	○	○	⊙	▲	▲	▲	▲	○	▲	▲	⊙	45
Quite travel	○	⊙	▲	○	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	○	29
Luxury	▲	○	⊙	○	⊙	⊙	○	▲	▲	▲	▲	▲	▲	▲	○	47
Personal work space w/internet	▲	▲	○	○	⊙	⊙	⊙	▲	▲	▲	▲	○	▲	▲	○	47
Nonstop continuous operation	○	▲	▲	▲	▲	▲	⊙	⊙	○	▲	○	○	▲	▲	○	38
Be on schedule all the time	○	▲	▲	▲	▲	▲	○	⊙	○	▲	⊙	▲	▲	▲	▲	37
Low impact on environment	▲	▲	▲	▲	○	▲	○	▲	▲	○	○	⊙	⊙	○	○	43
Safety	▲	▲	▲	▲	▲	▲	○	○	○	○	▲	▲	▲	⊙	▲	31
Low cost travel	⊙	○	○	○	○	○	○	○	○	▲	▲	⊙	○	○	⊙	59
Interactive applications for customer acquisition	▲	▲	▲	▲	▲	▲	▲	▲	○	▲	▲	▲	▲	▲	○	19
Reduce energy user	⊙	▲	▲	▲	○	○	⊙	○	▲	▲	○	⊙	○	▲	○	51
Reduce travel time	⊙	▲	▲	▲	▲	▲	○	○	▲	○	⊙	○	▲	▲	○	41
Positive impact on society	○	○	▲	▲	▲	▲	▲	▲	▲	▲	○	⊙	⊙	⊙	○	47
Score	47	29	27	23	37	35	57	37	23	19	37	53	33	33	47	

Fig. A2. QFD for fast train system design (economy).

Ranking	
Strong Relationship	⊙
Medium Relationship	○
Week Relationship	▲

Engineering Characteristics

Customer Requirements	Efficient Design	Noise Reduction/Dampening	Ergonomically Designed Seats	Maximize cabin volume	AC power for personal devices	High Speed Internet	Provide steady flow of power	Controls system design	Safe data collection system design	Regulations/policies	Appropriate Route Selection	Amount of energy consumption	Mass of air pollutant	Safety plan	Funding	Score
Low cost ticket price	○	▲	▲	○	○	○	▲	▲	▲	○	▲	○	▲	▲	⊙	35
Quite travel	○	⊙	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	25
Luxury	▲	⊙	⊙	⊙	⊙	⊙	○	▲	▲	▲	▲	▲	▲	▲	○	59
Personal work space w/internet	▲	○	⊙	⊙	⊙	⊙	○	▲	▲	▲	▲	▲	▲	▲	▲	51
Nonstop continuous operation	○	▲	▲	▲	▲	▲	⊙	⊙	⊙	○	○	○	▲	○	○	51
Be on schedule all the time	▲	▲	▲	▲	▲	▲	⊙	⊙	⊙	○	○	▲	▲	▲	▲	43
Low impact on environment	⊙	○	▲	▲	▲	▲	○	▲	○	○	▲	⊙	⊙	▲	▲	41
Safety	○	▲	▲	▲	▲	▲	○	⊙	⊙	○	▲	▲	▲	⊙	▲	45
Low cost travel	○	▲	▲	▲	▲	▲	○	▲	▲	○	▲	○	▲	▲	⊙	31
Interactive applications for customer acquisition	▲	▲	▲	▲	▲	▲	▲	▲	○	○	▲	▲	▲	▲	○	21
Reduce energy user	⊙	▲	▲	▲	▲	▲	⊙	⊙	⊙	▲	○	⊙	▲	▲	▲	57
Reduce travel time	⊙	▲	▲	▲	▲	▲	⊙	⊙	⊙	○	⊙	○	▲	▲	○	61
Positive impact on society	⊙	⊙	▲	▲	▲	▲	▲	▲	○	○	⊙	○	○	○	▲	49
Score	55	41	29	31	31	31	55	53	59	31	35	39	23	25	37	

Fig. A3. QFD for fast train system design (electric).

Ranking		
Strong Relationship	⊙	9
Medium Relationship	○	3
Week Relationship	▲	1

Customer Requirements \ Engineering Characteristics	Efficient Design	Noise Reduction/Dampening	Ergonomically Designed Seats	Maximize cabin volume	AC power for personal devices	High Speed Internet	Provide steady flow of power	Controls system design	Safe data collection system design	Regulations/policies	Appropriate Route Selection	Amount of energy consumption	Mass of air pollutant	Safety plan	Funding	Score
Low cost ticket price	⊙	▲	○	○	○	○	▲	▲	▲	▲	▲	○	▲	▲	○	35
Quite travel	○	⊙	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	25
Luxury	○	○	⊙	⊙	○	⊙	▲	▲	▲	▲	▲	▲	▲	▲	○	47
Personal work space w/internet	○	○	○	○	⊙	⊙	▲	▲	▲	▲	▲	▲	▲	▲	▲	39
Nonstop continuous operation	⊙	▲	○	○	▲	▲	⊙	⊙	○	⊙	○	○	▲	○	○	61
Be on schedule all the time	⊙	▲	▲	▲	▲	▲	⊙	⊙	○	○	▲	▲	▲	○	▲	45
Low impact on environment	⊙	▲	▲	▲	▲	▲	○	○	▲	▲	⊙	⊙	⊙	▲	▲	51
Safety	○	▲	▲	▲	▲	▲	○	⊙	▲	⊙	○	▲	▲	⊙	▲	36
Low cost travel	⊙	▲	○	○	○	○	▲	○	▲	▲	○	⊙	▲	○	⊙	53
Interactive applications for customer acquisition	▲	▲	▲	▲	▲	○	▲	▲	⊙	▲	▲	▲	▲	▲	▲	25
Reduce energy user	⊙	▲	▲	▲	○	○	▲	○	▲	▲	○	⊙	▲	▲	▲	39
Reduce travel time	○	▲	▲	▲	▲	▲	○	○	▲	○	⊙	▲	▲	▲	▲	31
Positive impact on society	▲	▲	▲	○	▲	▲	▲	▲	○	▲	○	○	○	○	▲	27
Score	71	25	29	31	29	37	35	45	27	33	39	43	23	29	27	

Fig. A4: QFD for fast train system design (mechanical).

Ranking		
Strong Relationship	⊙	9
Medium Relationship	○	3
Week Relationship	▲	1

Customer Requirements \ Engineering Characteristics	Efficient Design	Noise Reduction/Dampening	Ergonomically Designed Seats	Maximize cabin volume	AC power for personal devices	High Speed Internet	Provide steady flow of power	Controls system design	Safe data collection system design	Regulations/policies	Appropriate Route Selection	Amount of energy consumption	Mass of air pollutant	Safety plan	Funding	Score
Low cost ticket price	○			○							○	○				12
Quite travel	○	⊙														12
Luxury		○	⊙	⊙	⊙	⊙	○								○	45
Personal work space w/internet	○	○	○	○	⊙	⊙	⊙									39
Nonstop continuous operation	⊙						⊙	⊙				○				30
Be on schedule all the time	⊙						○	⊙								21
Low impact on environment	⊙									○	○	⊙	⊙			33
Safety								⊙	▲	⊙				⊙		28
Low cost travel	⊙			○				○				○				18
Interactive applications for customer acquisition									⊙						○	12
Reduce energy user	⊙						○	○			○	⊙				27
Reduce travel time	⊙						○	⊙			⊙	○				33
Positive impact on society	○						○	○	○		○	⊙	⊙	⊙		42
Score	66	15	12	18	18	18	33	45	13	12	21	39	18	18	6	

Fig. A5. QFD for fast train system design (social).

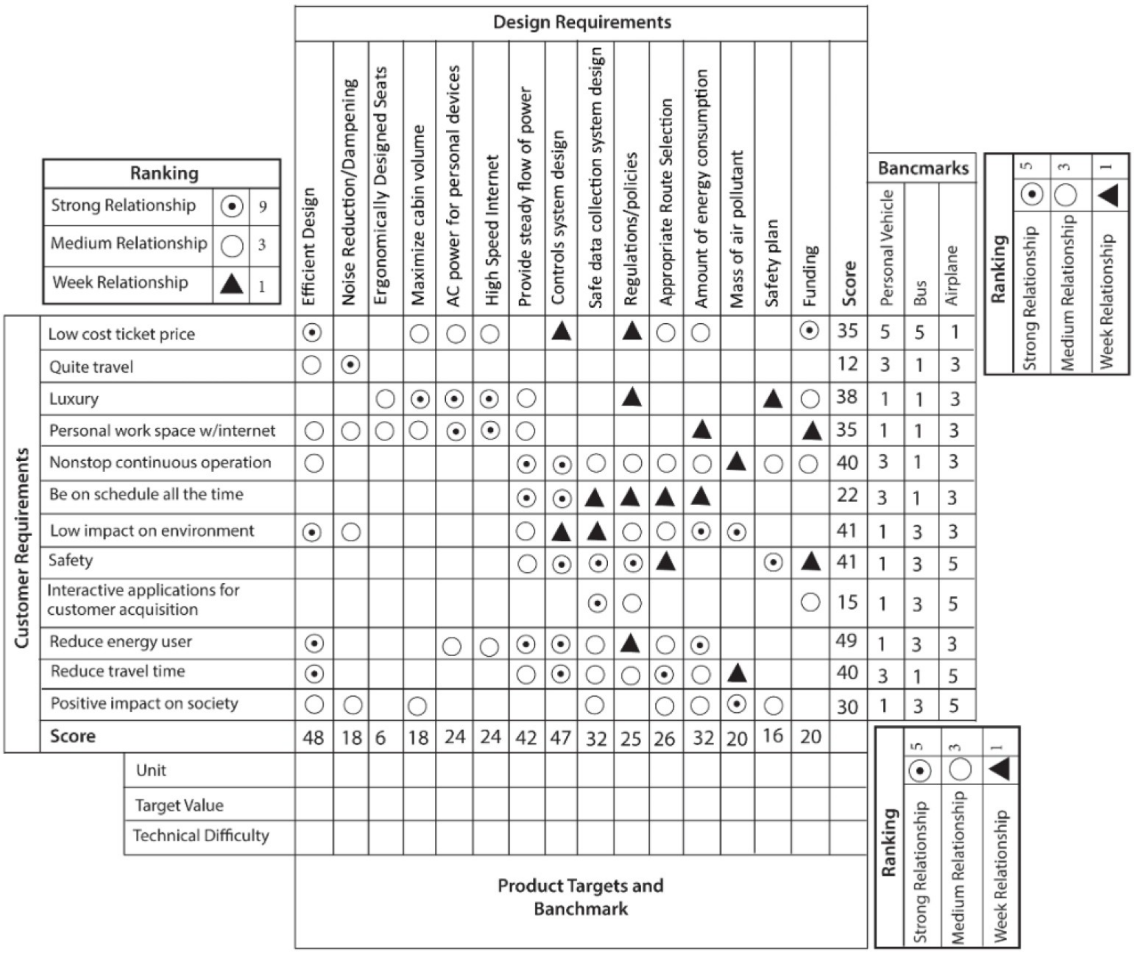

Fig. A6. QFD for High-Speed Train System Design through collective intelligence.

Utku Gulbulak, received his BS degree in Mechanical Engineering from Middle East Technical University, Turkey in 2014. He is a PhD candidate at Texas Tech University. His primary research interest is the development of the computational modeling of the systemic circulation in humans using multiphysics modeling. His secondary research interest is the impact of transdisciplinary education on engineering discipline.

Atila Ertas, PhD, Professor (2020 integrative Scholar of TTU) of Mechanical Engineering, received his masters and PhD from Texas A&M University. Dr. A. Ertas has been the driving force behind the conception and the development of the transdisciplinary model for education and research. His pioneering efforts in transdisciplinary research and education have been recognized internationally by several awards of Society for Design and Process Science (SDPS). Dr. Ertas creator of The Academy for Transdisciplinary Learning and Advanced Studies (ATLAS) as non-profit organizations that fund transdisciplinary research and educational activities. He has developed the Transdisciplinary Master of Engineering and Ph.D. Programs on Design, Process, and Systems in conjunction with the Raytheon Company in Dallas, Texas. This program has graduated over 140 students. Dr. Ertas has written numerous technical papers and modules on transdisciplinary education. He was a Senior Research Fellow of the ICC Institute at the University of Texas Austin, a Fellow of ASME, a Fellow of SDPS, and a Founding Fellow of Luminary Research Institute in Taiwan. He is also an honorary member of International Center for Transdisciplinary Research (CIRET), France. Dr. Ertas has earned both national and international reputation in engineering design. Dr. Ertas is the author of a number of books, among them: A. Ertas, and J. C. Jones, *The Engineering Design Process*, John Wiley & Sons, Inc., first addition 1993 and second edition 1996; A. Ertas, *Prevention through Design (PtD): Transdisciplinary Process*, funded by the National Institute for Occupational Safety and Health, 2010; A. Ertas, *Engineering Mechanics and Design Applications*, *Transdisciplinary Engineering Fundamentals*, CRC Press, Taylor & Francis Group, 2011; Ertas, A., "Transdisciplinarity Engineering Design Process, John Wiley & Sons, Inc., 2018; A. Ertas (editor), *Transdisciplinarity: Bridging Natural Science, Social Science, Humanities & Engineering*, The ATLAS Publications, 2011; B. Nicolescu and A. Ertas (editors), *Transdisciplinary Theory and Practice*, ATLAS Publications, 2013; Nicolescu, B., Ertas, A., (editors), "Transdisciplinary Education, Philosophy, & Applications'' ATLAS Publications, (Research Monograph), 2014; Ertas, A., Nicolescu, B., S. Gehlert, (editors), ''Convergence: Transdisciplinary Knowledge & Approaches to Education and Public Health,'' (Research Monograph), ATLAS Publishing, 2016. Dr. Ertas edited more than 35 conference proceedings. Dr. Ertas' contributions to teaching and research have been recognized by numerous honors and awards.

McKenzie Cordell, PhD received her BS degree in Psychology from the University of Kentucky in 2014. She received her M.A. in Psychology at Texas Tech University in 2016 and her PhD in Psychology at Texas Tech University in 2020. Her current research involves depression and alcohol use in male minority students, specifically considering masculinity and depression in Hispanic students. Her research interests broadly surround health psychology considering ethnic minorities. She is currently on her doctoral internship in Clinical Health Psychology at the Medical College of Georgia-Charlie Norwood VAMC.