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Transdisciplinary Educational Performance Evaluation through Survey*

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The purpose of this paper is to introduce the need for transdisciplinary graduate education in institutions of higher education and share the survey analysis and results with the readers. The survey was divided into four groups: research scientists, academics (faculty), industry/business persons, and graduate students. With over 134 responses, the data provided an abundance of useful information on transdisciplinary educational activities. A few items were clear in reporting the results of this survey. For example, 'Bringing together graduate students and faculty as well as researchers from diverse disciplines interested in transformative educational agendas for graduate studies through integrative transdisciplinary courses, lectures, and seminars' showed a very strong relationship to all the education objectives except the second one, namely 'To educate students broadly and prepare them for an increasingly transdisciplinary, collaborative, and global job market.' The analyses of the results suggest that individual group decisions are reasonably consistent with the entire group decision. Finally, it is concluded that the main factor, namely 'Enhancing a transdisciplinary dialogue between disciplinary courses,' is almost an exact match with all the groups' rankings and relationships.

Keywords: transdisciplinary education; international perspective

1. Introduction

Since the 1950s, integrating education and research methods and techniques across disciplines has been of great interest in the social and natural sciences [1]. A particular area of study is called a discipline if it has cohesive tools, specific techniques, specific methods, and a well developed disciplinary terminology. Because disciplines inevitably develop into self-contained shells, interaction with other disciplines is minimized. However, practitioners of a discipline develop effective intra-disciplinary communication based on their disciplinary vocabulary.

Multidisciplinary activities involve researchers from various disciplines working essentially independently, each from his or her own discipline-specific perspective, to address a common problem. Multidisciplinary teams do cross discipline boundaries; however, they remain limited to the framework of disciplinary research. In *Interdisciplinary activities*, researchers from different disciplines work jointly on common problems by exchanging methods, tools, and concepts among them to find integrated solutions. Both multidisciplinary and interdisciplinary activities exceed discipline boundaries but their goal remains within the framework of disciplinary research.

Over the last decade, there has been an explosion of complex problems facing engineers and a rapid evolution of the technical understanding in science and engineering that is needed to attack these problems. A few examples are the groundbreaking advancements in semi-conductor and software technologies, the bio-sciences, and nanotechnology. Large-scale, complex problems include not only the design of engineering systems with numerous components and subsystems that interact in multiple and intricate ways; they also involve the design, redesign, and interaction of social, political, managerial, commercial, religious, biological, medical, etc. systems. Further, these systems are likely to be dynamic and adaptive in nature. Solutions to such large-scale complex problems require many activities that cross discipline boundaries. A truly transdisciplinary research and educational system is needed to address large-scale complex problems and to educate the researchers and designers of the future.

Many distinguished researchers and educators contributed to the development of transdisciplinary education and research concepts. In German-speaking countries, the term 'transdisciplinarity' is used for integrative forms of research [2]. Transdisciplinary education and research programs take collaboration across discipline boundaries a step further than do multidisciplinary and interdisciplinary programs. The transdisciplinary concept is a process by which researchers representing diverse disciplines work jointly to develop and use a shared conceptual framework to solve a common problem. A central hallmark of transdisciplinary research is the loosening of theoretical models and the development of a new conceptual synthesis of common terms, measures, and methods that produce new theories and models [3]. The terms multidisciplinary, interdisciplinary, and transdisciplinary are often defined differently among researchers and educators.

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- Nicolescu stated that transdisciplinarity concerns that which is at once between the disciplines, across the different disciplines, and beyond all disciplines [4]. Klein defined the terminology of transdisciplinary approaches as: 'Transdisciplinary approaches are comprehensive frameworks that transcend the narrow scope of disciplinary world views through an overarching synthesis, such as general systems, policy sciences, feminism, ecology, and sociobiology' [5].
- Hadorn et al. stated that 'Transdisciplinary research is research that includes cooperation within the scientific community and a debate between research and the society at large. Transdisciplinary research therefore transgresses boundaries between scientific disciplines and between science and other societal fields and includes deliberation about facts, practices and values' [6].
- Peterson and Martin stated that interdisciplinary research has not produced a combination or synthesis that would go beyond disciplinary boundaries to produce innovative solutions to policy questions. However, transdisciplinary approaches call for a synthesis of research at the stages of conceptualization, design, analysis, and interpretation by integrated team approaches [7].
- Stokols et al. defined transdisciplinary science as collaboration among scholars representing two or more disciplines in which the collaborative products reflect an integration of conceptual and/or methodological perspectives drawn from two or more fields [8].
- Burger and Kamber characterized transdisciplinary science as cognitive and social cooperation across disciplinary boundaries [9].
- Bruce et al. defined multidisciplinary research as each discipline working in a self-contained manner, whereas with interdisciplinary research an issue is approached from a range of disciplinary perspectives integrated to provide a systemic outcome. Bruce et al. then defines the notion of transdisciplinary research as the organization of knowledge around complex heterogeneous domains rather than the disciplines and subjects into which knowledge is commonly organized [10].
- Cronin defined transdisciplinary studies as projects that integrate both academic researchers from different unrelated disciplines and non-academic participants to research a common goal and create new knowledge and theory. Transdisciplinarity combines interdisciplinarity with a participatory approach [11].
- McGregor stated that transdisciplinarity takes knowledge generated within disciplines, and moves it beyond the boundaries of these disciplines to make new connections between academia and civil society [12].

Around the world, universities are working to change their visions of education and research. Many innovative graduate programs and practices have been developed during the last 10 years; it is no longer true that graduate education is always discipline-oriented. Derry and Fischer stated the following: 'If the world of working and living relies on collaboration, creativity, definition and framing of problems and if it requires dealing with uncertainty, change, and intelligence that is distributed across cultures, disciplines, and tools—then graduate programs should foster transdisciplinary competencies that prepare students for having meaningful and productive lives in such a world' [13]. The goal of graduate education should be to prepare students to live and work productively in a world in which intelligence is distributed across networks of human and artifacts [13–16].

Ten years ago, the Texas Tech University College of Engineering had the vision to develop the first engineering transdisciplinary graduate education program on design, process, and systems, first in 1999 with the Master's and then in 2007 the Ph.D. This initiated the transdisciplinary education and research into the engineering community and workplace. Raytheon, a large U.S. defense contractor, was a prime supporter of the program. To date, well over 120 Raytheon employees have completed either the Master's or the Ph.D. degree programs.

A new Doctoral Program in Sustainability Studies offered by Stellenbosch University, South Africa, will provide participants with a unique educational experience that will equip them to respond to a global challenge of our time. The goal of the program will be sustainable development with a focus on the development and building of sustainable communities/neighborhoods in an African Urban context.

Claremont Graduate University has created new courses designed to broaden the experience of their Ph.D. students. Claremont has instituted a new transdisciplinary course requirement for all Ph.D. students. The courses are team taught around a theme. Each transdisciplinary course must include students from a range of disciplines, and they are required to undertake different types of research of their requirements [17]. Transdisciplinary model for education and research was discussed by other researchers and educators [18–21].

The results of transdisciplinary research and education are the emphasis on teamwork, bringing together multiple disciplines of investigators, and sharing the methodologies, all to create fresh, invigorating ideas that expand the disciplinary boundaries. The transdisciplinary approach develops in people the desire to seek collaboration outside the bounds of their professional experience to explore different perspectives [22].

The objective of this paper is to evaluate the transdisciplinary educational performance through an international survey.

2. Defining transdisciplinarity

During the last decade, other different approaches of transdisciplinarity were developed and described by several distinguished researchers and educators. From the definitions mentioned above, one can easily see that phrases of collaboration, shared knowledge, unity of knowledge, distributed knowledge, common knowledge, integration of knowledge, integrated disciplines, beyond discipline, complex problems, and societal fields are common. Although a precise definition of transdisciplinarity is debatable, after reviewing the above approaches, definitions, and common phrases, transdisciplinarity may be defined as follows:

- *Transdisciplinarity* is a development of new knowledge, concepts, tools, and technologies shared by researchers from different families of disciplines (social science, natural science, humanities, and engineering). It is a collaborative process for a new way of organized knowledge generation and integration by crossing disciplinary boundaries for designing and implementing solutions to unstructured problems.
- *Transdisciplinary knowledge* is a shared, common collection of knowledge from diverse disciplinary knowledge cultures (engineering, natural science, social science, and humanities).
- The *Transdisciplinary Research Process* can be defined as collaboration among scholars from diverse disciplines to develop and use integrated conceptual frameworks, tools, techniques, and methodologies to solve common unstructured research problems. Transdisciplinary research leads to the creation of new paradigms and provides pathways to new frontiers.

3. Survey development

The following key steps were used for the survey design and development:

- Define the objective of the survey
- Determine the target audience and sample
- Create relevant questions
- Run a pilot test
- Modify and finalize the questions
- Collect and compile the data
- Analyze the data.

The objective of the survey is to evaluate transdisciplinary educational performances. The survey participants were divided into four groups. They are research scientists, academics (faculty), industry/business people, and graduates. Although research scientists, academics (faculty), and industry/business people were from different organizations and countries, the graduate students were mainly from Texas Tech University Transdisciplinary Master's of Engineering program. These programs have graduated over 120 students.

3.1 Developing questions for the Transdisciplinary Education Process

Transdisciplinary Graduate Education Objectives are developed as shown below. The objectives will be called 'dependent variables' and the main factors will be called 'independent variables'.

Transdisciplinary Graduate Education Objectives were stated as:

- To prepare today's students to solve the complex and ill-defined real-world problems of the future
- To educate students broadly and prepare them for an increasingly transdisciplinary, collaborative, and global job market
- To prepare students to participate effectively in diverse collaborative organizations
- To provide students with the integrative thinking and skills required to identify, frame, and address important practical problems that cut across disciplinary boundaries
- To develop in students the ability to innovate and create
- To develop in students the habits for productive lifelong learning.

The main factors that the Transdisciplinary Graduate Education Process requires are:

- Enhancing a transdisciplinary dialogue between disciplinary courses
- Creating transdisciplinary fundamental courses that include and implement shared concepts, theories, and methods
- Bringing together graduate students and faculty as well as researchers from diverse disciplines interested in transformative educational agendas for graduate studies through integrative transdisciplinary courses, lectures, and seminars
- Defining a theoretical framework leading to a model for transdisciplinary graduate program.

The survey questions were developed (see Appendix) using the transdisciplinary education objectives and the requirements stated above.

4. Statistical approach to data analysis

One-way ANOVA can be used to test hypotheses regarding the equality of three or more treatments.

The basis of ANOVA is the partitioning of the sum of the squares into between-treatment sum of squares, $SS_{between}$ and within-treatment, SS_{within}. This will allow us to compare the observations with each other simultaneously rather than individually. In this analysis, we assume that samples are normally distributed.

The analysis can start by calculating total sum of squares as:

$$SS_T = SS_Y - C \tag{1}$$

where SS_Y is the sum of the squares of each observation *Y*, and *C* is the correction factor given by

$$SS_Y = \sum Y_i^2 \tag{2}$$

where Y_i is the observation

$$C = \frac{T^2}{N} \tag{3}$$

where *T* is the sum of all the observations and *N* is the total number of observation (total sample size).

Between-treatment variation

The sum of the squares between-treatments, $SS_{between}$, is the variation due to the interaction between the samples treatments given by

$$SS_{between} = \frac{L_1^2 + L_2^2 + L_3^2 + L_4^2}{n} - C \tag{4}$$

where *L* is the sum of the observations in each treatment and *n* is the sample size in each treatment. The mean square between-treatments, $MS_{between}$, is defined by

$$MS_{between} = \frac{SS_{between}}{\nu_{between}} \tag{5}$$

where $\nu_{between}$ is the degree of freedom for $SS_{between}$ given by

$$\nu_{between} = \text{number of groups} - 1 \tag{6}$$

Within-treatment variation

The sum of the squares within treatments, SS_{within}, is the variation due to differences within individual samples and is given by

$$SS_{within} = SS_T - SS_{between} \tag{7}$$

The mean square within treatments, MS_{within}, is calculated by

$$MS_{within} = \frac{SS_{within}}{\nu_{within}} \tag{8}$$

where ν_{within} is the degree of freedom for SS_{within} and given by

$$\nu_{within} = (n-1)k \tag{9}$$

or

$$\nu_{within} = N - k \tag{10}$$

where *k* is the number of treatments under consideration (in this case $k = 4$).

It is now possible to evaluate the null hypothesis using F test defined by

$$F = \frac{MS_{between}}{MS_{within}} \tag{11}$$

It should be noted that if $F << 1$, then it is likely that differences between treatment means exist. To test the hypothesis, the *F* value calculated by Equation (11) is compared with the critical value of *F*. The critical value of F_{cr} is determined from statistical tables using the degree of freedom between treatments and the degree of freedom within treatment values. If the value of *F* is greater than the value of F_{cr}, the probability of the obtained result occurring due to chance is low, hence we reject the null hypothesis.

In the case where there are more than two treatments of independent variables, statistical analysis should be carried out in two steps:

Step 1. Perform the *F* test to determine if any significant differences exist among any of the means. If the *F* test value is shown to be statistically significant, then we carry out a second step.

Step 2. In the second step, a post-hoc analysis should be performed to determine where the inequalities are. A post-hoc test is used when we have three or more means to compare. This test provides us with the critical difference between all possible two means. For this study, Fisher's protected t-test will be used. The formula is given by:

$$F_{compare} = \frac{(M_i - M_j)^2}{MS_{within}\left(\frac{1}{n_i} + \frac{1}{n_j}\right)} \tag{12}$$

where *i* and *j* are the treatments being compared, and n_i and M_i are the number of observations and the mean of treatment *i*, respectively. The test statistics will be performed for each pair of means by using the values of $F_{compare}$ and F_{cr}. Note that for the application of the protected t-test, F_{cr} is found by using df = 1 for the numerator and df_w (ν_{within}) for the denominator.

Table 1. Summary of survey responses by groups

Group	No. in group	% of respondents	Questions answered partially	Questions answered all
Researchers	61	45.9%	2	26
Academics	75	48.0%	3	33
Industry/Business	65	69.2%	3	42
Graduates	49	51.0%	1	24
Total	250	53.6%	9	125

5. Data analysis, results, and discussions

5.1 Relationship of transdisciplinary graduate education to main factors

A survey of transdisciplinary education was conducted, starting in June 2009, and continued for five weeks. With over 134 responses, the data provide an abundance of useful information on transdisciplinary educational activities. The results of the survey by groups are shown in Table 1. Some of the results were about what we expected, and only a very few of them surprised us. The response rate for the survey was better than expected. The total response rate was 53.6%, and in every category the response rate reaches at least 45.9%. The general relationship metric used in the analysis is shown in Table 2.

Table 3 shows the relationship of transdisciplinary graduate education to main factors that the transdisciplinary education process requires for the researchers' group. As shown in Table 3, the main factor, 3, showed a very strong relationship to all the education objectives except the second one.

Table 2. Relationship metric used in the analysis

S	Indicates *strong* relationship (4 ≤ rating ≤ 5)
M	Indicates *medium* relationship (3 ≤ rating < 4)
W	Indicates *weak* relationship (2 ≤ rating < 3)
N	Indicates *no* relationship (2 ≥ rating)

The survey results suggest that the objective 'to *develop in students the habits for productive lifelong learning,'* has a weak relationship to the main effect of '*defining a theoretical framework leading to a model for transdisciplinary graduate program.'*

Table 4 shows the relationship of transdisciplinary graduate education to the main factors that the transdisciplinary education process requires for the academics group. As shown in Table 4, some strong relationships were observed. For example, the main factor of *creating transdisciplinary fundamental courses that include and implement shared concepts, theories, and methods* showed strong relationships with the education objective of 1, 4, and 5. On the other hand, the main factor of *bringing together graduate students and faculty as well as researchers from diverse disciplines interested in transformative educational agendas for graduate studies methods through integrative transdisciplinary courses, lectures, and seminars* showed strong relationships with all of the education objectives with the exception of the first objective. Survey results revealed that no weak relationship was observed in this group.

Table 5 shows the relationship of transdisciplinary graduate education to the main factors that the transdisciplinary education process require for the business/industry group. It is clear from Table 5 that the majority of the relationships were medium. The

Table 3. Relationship of transdisciplinary graduate education objectives to the main factors: Researchers

	Main factors to accomplish objectives			
Transdisciplinary graduate education objectives	**1**	**2**	**3**	**4**
To prepare today's students to solve the complex and ill-defined real-world problems of the future	M	S	S	M
To educate students broadly and prepare them for an increasingly transdisciplinary, collaborative, and global job market	M	M	M	S
To prepare students to participate effectively in diverse collaborative organizations	M	M	S	M
To provide students with the integrative thinking and skills required to identify, frame and address important practical problems that can cut across disciplinary boundaries	M	S	S	M
To develop in students the ability to innovate and create	M	M	S	M
To develop in students the habits for productive lifelong learning	M	M	S	W

Main factors
1. Enhancing a transdisciplinary dialogue between disciplinary courses
2. Creating transdisciplinary fundamental courses that include and implement shared concepts, theories, and methods
3. Bringing together graduate students and faculty as well as researchers from diverse disciplines interested in transformative educational agendas for graduate studies through integrative transdisciplinary courses, lectures, and seminars
4. Defining a theoretical framework leading to a model for transdisciplinary graduate program

Table 4. Relationship of transdisciplinary graduate education objectives to the main factors: Academics

	Main factors to accomplish objectives			
Transdisciplinary graduate education objectives	**1**	**2**	**3**	**4**
To prepare today's students to solve the complex and ill-defined real-world problems of the future	M	S	M	M
To educate students broadly and prepare them for an increasingly transdisciplinary, collaborative, and global job market	M	M	S	S
To prepare students to participate effectively in diverse collaborative organizations	S	M	S	M
To provide students with the integrative thinking and skills required to identify, frame and address important practical problems that can cut across disciplinary boundaries	M	S	S	M
To develop in students the ability to innovate and create	M	S	S	M
To develop in students the habits for productive lifelong learning	M	M	S	M

Main factors
1. Enhancing a transdisciplinary dialogue between disciplinary courses
2. Creating transdisciplinary fundamental courses that include and implement shared concepts, theories, and methods
3. Bringing together graduate students and faculty as well as researchers from diverse disciplines interested in transformative educational agendas for graduate studies through integrative transdisciplinary courses, lectures, and seminars
4. Defining a theoretical framework leading to a model for transdisciplinary graduate program

rankings given by the people in this group were below 4 in almost every education objective with respect to the main factors.

Table 6 shows the relationship of transdisciplinary graduate education to the main factors that the transdisciplinary education process requires for the graduates group. As shown in Table 6, the majority of the relationships were medium and very scattered. No weak relationship was observed.

So far, we have analyzed the ranking of transdisciplinary education from researchers, academics, business/industry and graduates groups. The collection of rankings from each group may not represent the entire group interest. To check whether the ranking by each group is consistent with the entire group observation, we put the entire data collection for ranking from all the groups into a combined grouping. Table 7 shows the relationship of transdisciplinary graduate education to the main factors that the transdisciplinary education process requires for the entire group. As shown in Table 7, the relationship is scattered, as we have observed in individual group rankings. It is clear that the main factor 1 is almost an exact match with all the groups' rankings and relationships. In conclusion, we may say that, ideally, we discuss the situation, look at it from all sides, and evaluate the results. The analyses of the results suggest that individual group decisions are reasonably consistent with the entire group decision.

Now, consider transdisciplinary graduate education objectives (provide survey questions) and main

Table 5. Relationship of transdisciplinary graduate education objectives to the main factors: Business/Industry people

	Main factors to accomplish objectives			
Transdisciplinary graduate education objectives	**1**	**2**	**3**	**4**
To prepare today's students to solve the complex and ill-defined real-world problems of the future	M	M	M	M
To educate students broadly and prepare them for an increasingly transdisciplinary, collaborative, and global job market	M	M	M	S
To prepare students to participate effectively in diverse collaborative organizations	M	M	S	M
To provide students with the integrative thinking and skills required to identify, frame and address important practical problems that can cut across disciplinary boundaries	M	S	M	M
To develop in students the ability to innovate and create	M	M	S	M
To develop in students the habits for productive lifelong learning	M	M	M	M

Main factors
1. Enhancing a transdisciplinary dialogue between disciplinary courses
2. Creating transdisciplinary fundamental courses that include and implement shared concepts, theories, and methods
3. Bringing together graduate students and faculty as well as researchers from diverse disciplines interested in transformative educational agendas for graduate studies through integrative transdisciplinary courses, lectures, and seminars
4. Defining a theoretical framework leading to a model for transdisciplinary graduate program

Table 6. Relationship of transdisciplinary graduate education objectives to the main factors: Graduates

	Main factors to accomplish objectives			
Transdisciplinary graduate education objectives	**1**	**2**	**3**	**4**
To prepare today's students to solve the complex and ill-defined real-world problems of the future	M	M	M	M
To educate students broadly and prepare them for an increasingly transdisciplinary, collaborative, and global job market	S	M	M	S
To prepare students to participate effectively in diverse collaborative organizations	M	M	S	M
To provide students with the integrative thinking and skills required to identify, frame and address important practical problems that can cut across disciplinary boundaries	M	S	M	M
To develop in students the ability to innovate and create	M	M	S	M
To develop in students the habits for productive lifelong learning	M	M	M	M

Main factors
1. Enhancing a transdisciplinary dialogue between disciplinary courses
2. Creating transdisciplinary fundamental courses that include and implement shared concepts, theories, and methods
3. Bringing together graduate students and faculty as well as researchers from diverse disciplines interested in transformative educational agendas for graduate studies through integrative transdisciplinary courses, lectures, and seminars
4. Defining a theoretical framework leading to a model for transdisciplinary graduate program

factors (provide treatments) for the ANOVA analysis. Assuming graduate education objectives are null hypotheses, we have the following.

5.2 Application of one-way ANOVA

Researchers' group

For this case, there are 28 samples for each of the three treatments (total number of observations is $N = 112$). All the ANOVA results for the researchers group are given in Table 8. Calculated and critical F values are shown in Table 9. Question 1 corresponds to the first objective of transdisciplinary education with four treatments (main factors). They are Treatments A, B, C, and D. Then question 1 should read as: Which treatment is significant *to prepare today's students to solve the complex and ill-defined real-world problems of the future*? Assuming the confidence interval is 95% and the degrees of freedom are 3 and 108 (see Table 8, question 1), we obtain the critical value for F of approximately 3.25. Since the calculated value of $F = 4.32$ is larger than the critical value of F_{cr}, we conclude that question 1 is statistically significant. Now, we use *Fisher's protected t-test* to understand where the significant difference lies. With four treatments (Treatments A, B, C, and D), the following four comparisons between pairs of means are possible (see Table 10). Fisher's protected t-test results for all the questions under t-test are shown in Table 11. Note that question 4 is eliminated from further study since the calculated F value is less than the critical value of F for question 4.

When comparing the critical value of $F_{cr} = 5.18$ ($df = 1$ for the numerator and $df_w = 108$ for the denominator) with the calculated Fisher values, we can say that the significant difference lies only between the treatment pair (C and D) because the

Table 7. Relationships of transdisciplinary education objectives to the main factors: Entire group

	Main factors to accomplish objectives			
Transdisciplinary graduate education objectives	1	2	3	4
To prepare today's students to solve the complex and ill-defined real-world problems of the future	M	S	M	M
To educate students broadly and prepare them for an increasingly transdisciplinary, collaborative, and global job market	M	M	M	S
To prepare students to participate effectively in diverse collaborative organizations	M	M	S	M
To provide students with the integrative thinking and skills required to identify, frame and address important practical problems that can cut across disciplinary boundaries	M	S	M	M
To develop in students the ability to innovate and create	M	M	S	M
To develop in students the habits for productive lifelong learning	M	M	M	M

Main factors
1. Enhancing a transdisciplinary dialogue between disciplinary courses
2. Creating transdisciplinary fundamental courses that include and implement shared concepts, theories, and methods
3. Bringing together graduate students and faculty as well as researchers from diverse disciplines interested in transformative educational agendas for graduate studies through integrative transdisciplinary courses, lectures, and seminars
4. Defining a theoretical framework leading to a model for transdisciplinary graduate program

Table 8. Summary of ANOVA tables for researchers' group

Question 1					**Question 2**				
SOURCE	SS	df	MS	F	SOURCE	SS	df	MS	F
Between	10.74	3	3.58	4.32	Between	17.74	3	5.91	6.18
Within	89.54	108	0.83		Within	103.32	108	0.96	
Total	100.28	111			Total	121.06	111		
Question 3					**Question 4**				
SOURCE	SS	df	MS	F	SOURCE	SS	df	MS	F
Between	15.29	3	5.1	4.38	Between	5.62	3	1.87	1.86
Within	121.04	104	1.16		Within	100.38	100	1	
Total	136.32	107			Total	106	103		
Question 5					**Question 6**				
SOURCE	SS	df	MS	F	SOURCE	SS	df	MS	F
Between	17.88	3	5.96	5.29	Between	17.57	3	5.86	4.58
Within	112.65	100	1.13		Within	127.96	100	1.28	
Total	130.53	103			Total	145.53	103		

calculated Fisher value (12.48) is greater than the critical value of $F_{cr} = 5.18$. In other words, the treatment (C and D) pair is significantly different from the other pairs to prepare today's students to solve the complex and ill-defined real-world problems of the future. Although the degree of freedom for questions 1, 2, 3, 5, and 6 are slightly different, the critical value of F_{cr} will remain in the neighborhood of 5.18. Therefore, with the exception of question 4 (the calculated $F = 1.86$ is less than the critical $F_{cr} = 3.27$, see Table 9), all the other questions for this case are statistically significant. Note that the (A and B) pair has no significant effect on questions 1, 2, 3, 5, and 6 shown in Table 11. The (C and D) pair has a significant effect on all the questions except question 2. Table 11 shows that a significant difference lies between treatments (A and D), treatments (B and C) and treatments (B and D) for question 2. For questions 3 and 5, a significant difference lies between treatments (B and C) and treatments (C and D), whereas for question 6, a significant difference lies only between treatments (C and D).

Table 9. Summary of values of F and F_{cr}

Question	F	F_{cr}
1	*4.32*	*3.25*
2	*6.18*	*3.25*
3	*4.38*	*3.26*
4	1.86	3.27
5	*5.29*	*3.27*
6	*4.58*	*3.27*

Table 10. Pairs of four treatments

Pairs
A vs. B
A vs. C
A vs. D
B vs. C
B vs. D
C vs. D

Academics' group

For this case, there are 36 samples for each of the three treatments (total number of observations is $N = 144$). The results of the one-way ANOVA are shown in Table 12.

The summary of values of F and F_{cr} for the *academics'* group are given in Table 13. As seen from this table, the results of the calculated F values for all the questions except question 3 are smaller than the critical F_{cr} values. Hence, we accept the null and conclude that there are no significant differences with regards to the questions concerned. Since the calculated F value (3.50) is higher than the critical value of F_{cr}=3.21 for question 3, we conclude that there is a significant difference with regard to this question.

From Table 14, when comparing the critical value of $F_{cr} = 5.12$ with the calculated Fisher values, it is concluded that a significant difference lies only between treatments (A and D) and (C and D) pairs. In other words, to prepare students to participate effectively in diverse collaborative organizations, (A and D) and (C and D) pair treatments are significantly different from others. The treatment D, which is 'Defining a theoretical framework leading to a model for transdisciplinary graduate program,' is the most dominant main factor.

Business/Industry group

For this case, there are 45 samples for each of the three treatments (total number of observations is N

Table 11. Calculated protected t-test Fisher values

Question	1	2	3	5	6
A–B	0.55	1.23	0.62	1.11	0.12
A–C	4.92	1.49	4.05	3.35	4.84
B–C	2.19	*5.43*	*7.83*	*8.31*	3.42
A–D	1.73	*8.87*	1.96	3.87	2.24
B–D	4.22	*16.70*	0.38	0.84	3.42
C–D	*12.48*	3.09	*11.64*	*14.43*	*13.67*
F_{cr}	5.18	5.18	5.19	5.20	5.20

Table 12. Summary of ANOVA tables for academics' group

Question 1					**Question 2**				
SOURCE	SS	df	MS	F	SOURCE	SS	df	MS	F
Between	5.32	3	1.77	1.83	Between	2.9	3	0.97	1.03
Within	127.94	132	0.97		Within	123.91	132	0.94	
Total	133.26				Total	126.82			
Question 3					**Question 4**				
SOURCE	SS	df	MS	F	SOURCE	SS	df	MS	F
Between	10.29	3	3.43	3.5	Between	1.55	3	0.52	0.5
Within	129.59	132	0.98		Within	132.97	128	1.04	
Total	139.88				Total	134.52			
Question 5					**Question 6**				
SOURCE	SS	df	MS	F	SOURCE	SS	df	MS	F
Between	1.84	3	0.61	0.54	Between	9.54	3	3.18	2.71
Within	146.24	128	1.14		Within	149.94	128	1.17	
Total	148.08				Total	159.48			

Table 13. Summary of values of F and F_{cr} for academics' group

Question	F	F_{cr}
1	1.83	3.21
2	1.03	3.21
3	*3.50*	*3.21*
4	0.50	3.21
5	0.54	3.21
6	2.71	3.21

Table 14. Calculated protected t-test Fisher values

Question	**7**
A–B	2.64
A–C	0.21
B–C	4.34
A–D	*5.44*
B–D	0.50
C–D	*7.79*
F_{cr}	5.12

= 180). The results of the one-way ANOVA are shown in Table 15.

As shown in Table 16, all the questions are statistically significant except question 6. Table 17 reveals that a significant difference for question 1 lies between treatments (A and B), (A and C), and (B and D); for question 2, treatments (A and B), (B and D) and (C and D); for question 3, treatments (A and D), (B and D) and (C and D); for question 4, treatment (B and D); and for question 5, treatments (A and C) and (C and D). In this case, it is concluded that the main factors B and D are the most dominant ones.

Graduate group

For this case, there are 25 samples for each of the three treatments (total number of observations is $N = 100$). The results of the one-way ANOVA are shown in Table 18.

As shown in Table 19, questions 2, 3, and 5 are statistically significant. Table 20 reveals that the significant difference for question 2 lies between treatments (A and B), (A and C), and (B and D); for question 3, treatments (A and D) and (C and D); and for question 5, only treatment (C and D). In this case, we concluded that the main factor D is the most dominant one. Namely, defining a theoretical

Table 15. Summary of ANOVA tables for the business/ industry group

Question 1					**Question 2**				
SOURCE	SS	df	MS	F	SOURCE	SS	df	MS	F
Between	12.9	3	4.3	3.6	Between	18.86	3	6.3	5.5
Within	199.5	168	1.2		Within	190.7	168	1.1	
Total	212.4	171			Total	209.5	171		
Question 3					**Question 4**				
SOURCE	SS	df	MS	F	SOURCE	SS	df	MS	F
Between	20.81	3	6.9	5.7	Between	12.43	3	4.1	3.5
Within	203.3	168	1.2		Within	194.9	164	1.2	
Total	224.1	171			Total	207.3	167		
Question 5					**Question 6**				
SOURCE	SS	df	MS	F	SOURCE	SS	df	MS	F
Between	13.92	3	4.6	3.6	Between	3.64	3	1.2	0.8
Within	210.4	164	1.3		Within	244.2	164	1.5	
Total	224.3	167			Total	247.9	167		

Table 16. Summary of values of F and F_{cr} for the business/industry group

Question	***F***	F_{cr}
1	*3.62*	*3.20*
2	*5.54*	*3.20*
3	*5.73*	*3.20*
4	*3.49*	*3.20*
5	*3.62*	*3.20*
6	0.81	3.20

Table 17. Calculated protected t-test Fisher values for business/industry

Question	**1**	**2**	**3**	**4**	**5**
A–B	*6.08*	*8.04*	0.01	4.41	1.90
A–C	*5.47*	3.20	2.84	1.48	*5.91*
B–C	0.02	1.10	3.13	0.78	1.11
A–D	0.03	0.69	*5.98*	0.78	0.32
B–D	*5.27*	*13.43*	*5.57*	*8.90*	3.78
C–D	4.70	*6.85*	*17.06*	4.41	*8.98*
F_{cr}	5.10	5.10	5.10	5.08	5.08

framework leading to a model for a transdisciplinary graduate program is the most effective main factor of the transdisciplinary education objectives.

Educational programs face numerous difficulties because of the constant change of technology in today's environment. Educational systems can respond to these changes by introducing the new concept of transdisciplinary education. During the last ten years many transdisciplinary training programs have started in the United States and other parts of the world. While the transdisciplinary education and research approach, in theory, should lead to a better outcome, it has potential disadvantages [23]. Among them are (a) the budget for transdisciplinary studies will be potentially higher and the approach creates additional extra cost to the universities; (b) the effort of achieving breadth of analysis and integration may encourage superficial investigation; (c) bringing together researchers from diverse disciplines into a collaborative team is an enormous challenge; (d) the considerable time and money required for transdisciplinary activities may decrease the participants' abilities to assess the outcome objectively and (e) the tenure and promotion of the participating faculty in the transdisciplinary studies could be in danger. The transdisciplinary educational model is radically different from traditional educational patterns and the development of transdisciplinary educational programs in today's universities will be difficult but well worth the effort. The concept of transcending the traditional disciplines stands in complete contradiction to the classical university organization around disciplinary colleges and departments. Although it is not essential to completely reorganize the entire university according to the transdisciplinary educational model, it may be necessary to create a

Table 18. Summary of ANOVA tables for the graduate group

Question 1

SOURCE	SS	df	MS	F
Between	6.54	3	2.2	1.6
Within	122.4	92	1.3	
Total	129	95		

Question 2

SOURCE	SS	df	MS	F
Between	14.86	3	5	4.4
Within	103.4	92	1.1	
Total	118.2	95		

Question 3

SOURCE	SS	df	MS	F
Between	17.11	3	5.7	5
Within	105.1	92	1.1	
Total	122.2	95		

Question 4

SOURCE	SS	df	MS	F
Between	6.2	3	2.1	1.7
Within	114.5	92	1.3	
Total	120.7	95		

Question 5

SOURCE	SS	df	MS	F
Between	13.5	3	4.5	3.3
Within	125.8	92	1.4	
Total	139.3	95		

Question 6

SOURCE	SS	df	MS	F
Between	4.42	3	1.5	1
Within	140.1	92	1.5	
Total	144.5	95		

Table 19. Summary of values of F and F_{cr} for the graduate group

Question	***F***	F_{cr}
1	1.64	3.28
2	*4.41*	*3.28*
3	*4.99*	*3.28*
4	1.66	3.28
5	*3.29*	*3.28*
6	0.97	3.28

Table 20. Calculated protected t-test Fisher values for the graduate group

Question	**2**	**3**	**5**
A–B	*9.07*	0.46	0.00
A–C	*5.40*	1.52	4.93
B–C	0.47	3.66	4.93
A–D	0.09	*6.57*	0.55
B–D	*7.38*	3.54	0.55
C–D	4.12	*14.41*	*8.76*
F_{cr}	5.22	5.22	5.22

transdisciplinary structure in which partial transdisciplinary programs can exist and from which collaboration with the existing structure of disciplines can be effected [17].

6. Conclusions

In this paper, the authors introduced transdisciplinary educational performance evaluation through a survey using four different groups: research scientists, academics (faculty), industry/business people, and graduates. A survey was developed and processed to understand and assess the importance of transdisciplinary education and its activities. One of the important findings was that the main factor 3—'Bringing together graduate students and faculty as well as researchers from diverse disciplines interested in transformative educational agendas for graduate studies through integrative transdisciplinary courses, lectures, and seminars,'—showed a very strong relationship with all the education objectives except the second one, 'To educate students broadly and prepare them for an increasingly transdisciplinary, collaborative, and global job market.' The analyses of the results suggest that individual group decisions are reasonably consistent with the entire group decision. Finally, it is concluded that the main factor 1 is almost an exact match with all the groups' rankings and relationships.

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Appendix

Question 1

Please rank the items from 1 to 5 according to what is most important when looking 'to prepare today's students to solve the complex and ill-defined real-world problems of the future.' Place a 1 next to the item that is least important and place a 5 next to the item that is most important.

—— Enhancing a transdisciplinary dialogue between disciplinary courses (treatment A).
—— Creating transdisciplinary fundamental courses that include and implement shared concepts, theories, and methods (treatment B).
—— Through integrative transdisciplinary courses, lectures and seminars bringing together graduate students and faculty as well as researchers from diverse disciplines interested in transformative educational agendas for graduate studies (treatment C).
—— Defining a theoretical framework leading to a model for a transdisciplinary graduate program (treatment D).

Question 2

Please rank the items from 1 to 5 according to what is most important when looking ‘to educate students broadly and prepare them for an increasingly transdisciplinary, collaborative, and global job market.’ Place a 1 next to the item that is least important and place a 5 next to the item that is most important.

—— Enhancing a transdisciplinary dialogue between disciplinary courses (treatment A).
—— Creating transdisciplinary fundamental courses that include and implement shared concepts, theories, and methods (treatment B).
—— Through integrative transdisciplinary courses, lectures and seminars bringing together graduate students and faculty as well as researchers from diverse disciplines interested in transformative educational agendas for graduate studies (treatment C).
—— Defining a theoretical framework leading to a model for a transdisciplinary graduate program (treatment D).

Question 3

Please rank the items from 1 to 5 according to what is most important when looking ‘to prepare students to participate effectively in diverse collaborative organizations.’ Place a 1 next to the item that is least important and place a 5 next to the item that is most important.

—— Enhancing a transdisciplinary dialogue between disciplinary courses (treatment A).
—— Creating transdisciplinary fundamental courses that include and implement shared concepts, theories, and methods (treatment B).
—— Through integrative transdisciplinary courses, lectures and seminars bringing together graduate students and faculty as well as researchers from diverse disciplines interested in transformative educational agendas for graduate studies (treatment C).
—— Defining a theoretical framework leading to a model for a transdisciplinary graduate program (treatment D).

Question 4

Please rank the items from 1 to 5 according to what is most important when looking ‘to provide students with the integrative thinking and skills required to identify, frame and address important practical problems that cut across disciplinary boundaries.’ Place a 1 next to the item that is least important and place a 5 next to the item that is most important.

—— Enhancing a transdisciplinary dialogue between disciplinary courses (treatment A).
—— Creating transdisciplinary fundamental courses that include and implement shared concepts, theories, and methods (treatment B).
—— Through integrative transdisciplinary courses, lectures and seminars bringing together graduate students and faculty as well as researchers from diverse disciplines interested in transformative educational agendas for graduate studies (treatment C).
—— Defining a theoretical framework leading to a model for a transdisciplinary graduate program (treatment D).

Question 5

Please rank the items from 1 to 5 according to what is most important when looking ‘to educate students with the ability of innovation and creation.’ Place a 1 next to the item that is least important and place a 5 next to the item that is most important.
—— Enhancing a transdisciplinary dialogue between disciplinary courses (treatment A).

—— Creating transdisciplinary fundamental courses that include and implement shared concepts, theories, and methods (treatment B).
—— Through integrative transdisciplinary courses, lectures and seminars bringing together graduate students and faculty as well as researchers from diverse disciplines interested in transformative educational agendas for graduate studies (treatment C).
—— Defining a theoretical framework leading to a model for a transdisciplinary graduate program (treatment D).

Question 6

Please rank the items from 1 to 5 according to what is most important when looking 'to educate students with the ability and habits for productive lifelong learning**.**' Place a 1 next to the item that is least important and place a 5 next to the item that is most important.

—— Enhancing a transdisciplinary dialogue between disciplinary courses (treatment A).
—— Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods (treatment B).
—— Through integrative transdisciplinary courses, lectures and seminars bringing together graduate students and faculty as well as researchers from diverse disciplines interested in transformative educational agendas for graduate studies (treatment C).
—— Defining a theoretical framework leading to a model for transdisciplinary graduate program (treatment D).

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 established The Academy for Transdisciplinary Learning and Advanced Studies (TheATLAS) as non-profit organizations that fund transdisciplinary research and educational activities. In 2008, he created a non-profit organization called International Transdisciplinary Scientists' Village (Its-Village). Currently, he is the founding president of this organization and looking for extraordinary people to develop the organization. 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 120 students. Dr. Ertas has written numerous technical papers and modules on transdisciplinary education. He is a Senior Research Fellow of the ICC Institute at the University of Texas Austin, a Fellow of ASME, and a Fellow of SDPS. Dr. Ertas has earned both national and international reputation in engineering design. Dr. Ertas is co-editor of more than 35 conference proceedings, senior co-author of transdisciplinary design textbook, The Engineering Design Process. Three of Dr. Ertas' design projects completed at Texas Tech University have won national awards. Dr. Ertas' contributions to teaching and research have been recognized by numerous honors and awards. The honors and awards include: President's Excellence in Teaching; Pi Tau Sigma Best Professor Award; Pi Tau Sigma Outstanding Teaching Award; Halliburton Award in recognition of outstanding achievement and professionalism in education and research; College of Engineering Outstanding Researcher Award; George T. and Gladys Hanger Abell Faculty Award for overall excellence in teaching and research; and President's Academic Achievement Award. He also received the most prestigious SDPS George Kozmetsky Distinguished Achievement Award and Excellence in Leadership Award. Most recently, he was recognized as one of the distinguished former students of Texas A&M, Mechanical Enginering Department. He has published over 150 scientific papers that cover many engineering technical fields. He has been PI or Co-PI on over 50 funded research projects. Under his supervision more than 180 MS and Ph.D. graduate students have received degrees.

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