Results of a Survey to Identify Differences between Interdisciplinary and Transdisciplinary Research Process

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Because of the rise in new technological and scientific discoveries and products, the disciplines have multiplied rapidly into disciplinary, multidisciplinary, interdisciplinary, and now transdisciplinary in the fields of natural science, social science, engineering and technology, humanities, arts, and the professional or applied arts and sciences. The numbers of disciplines, subdisciplines, and fields of study have grown from less than twenty-five to well over eight thousand and are still growing rapidly. The majority have been developed in the last one hundred years with the bulk developing in the years since World War II ended in 1945. The main objective of this chapter is to discuss the results of a survey conducted to compare interdisciplinary and transdisciplinary research requirements.
Keywords*:* survey for transdisciplinarity, transdisciplinary research, transdisciplinary concept.

1 Introduction

Over the last six decades the integration of research methods and techniques across the disciplines has changed rapidly. One of the prime reasons this change has occurred can be attributed to the rapid period of rebuilding following World War II in Europe, the Middle-East, and the Far East. The rebuild was followed closely by the technology growth driven by the USSR/USA race into space exploration. This created the quick start mechanism for growth in science and technology. The last forty years have seen the rest of the world catching up and in many cases surpassing the earlier leaders. The excitement continues to amaze us.

Because of the rise in new technological and scientific discoveries and products, the disciplines have multiplied rapidly into disciplinary, multidisciplinary, interdisciplinary, and now transdisciplinary in the fields of natural science, social science, engineering and technology, humanities, arts, and the professional or applied arts and sciences. The numbers of disciplines, sub-disciplines, and fields of study have grown from less than twenty-five to well over eight thousand and are still growing rapidly [1]. The majority have been developed in the last one hundred years with the bulk developing in the years since World War II ended in 1945.

The disciplines throughout history have inevitably

developed into self–contained shells, where interaction with other disciplines is minimized. However, practitioners of a discipline develop effective intra-disciplinary communication based on their disciplinary vocabulary. Suddenly the rapid growth in the numbers of disciplines, sub-disciplines and fields of study has created the need to start working new and complex findings or issues in different ways and the response has created intradisciplinary, multidisciplinary, interdisciplinary, and transdisciplinary as the possible answers. Once again the majority of these answers have occurred in the last sixty plus years.

2 Defining the Challenge

All over the world universities are working to change their visions of education and research. Twelveyears ago, Texas Tech University, College of Engineering had the vision to develop the first transdisciplinary design, process and systems master degree program, thus initiating transdisciplinary education and research into the engineering community and workplace. Moreover, four years ago the Ph.D program in Transdisciplinary Design, Process and Systems was introduced by Texas Tech University. Raytheon, a large U.S. defense contractor, is a prime supporter of the program. To date well over 130 Raytheon employees have completed the master's degree program.

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

This planet is becoming increasingly interconnected as new opportunities and highly complex problems tie us to the rest of the world in ways we are only beginning to understand. When we dont solve these problems correctly and in a timely manner, they rapidly become crises. These problems, such as hunger and the global water crisis, threaten the very existence of the planet as we know it. For example, a new crisis is emerging, a global food catastrophe that will reach further and be more crippling than anything the world has ever seen [2]. One of the largest public health issues of our time is the world water crisis. Nearly 2.5 billion people (roughly 2/5ths of the world's population) lack access to safe drinking water and sanitation [3]. A rising tsunami of energy problems is beginning to endanger the economy of the world and human living conditions. Finally, issues related to transportation, humanitarian needs, security, natural disasters, health, international development, ethnic violence and terrorism, military conflict, and emergency response are among the many global complex problems facing mankind in the 21st century. There is a need for transdisciplinary research to tackle the ill-defined problems of this century. Many distinguished researchers and educators contributed for the development of transdisciplinary education and research concepts [1, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17].

The main objective of this chapter is to discuss the results of a survey conducted to compare transdisciplinary and interdsisciplinary research requirements.

3 Comparison of Interdisciplinary and Transdisciplinary Research

The history of the term "Interdisciplinary" goes back to 1944 when it was used for the first time in the literature. Being a relatively new term, "transdisciplinary" first appeared in 1970. As seen from Figure 1, the most commonly used term "Multidisciplinary" has had over 18,000 citations by the year 2006 [18].

Many contributions exist in the open literature about the difference between interdisciplinary and transdisciplinary activities and their definitions. Bruce et al. stated that, in multidisciplinary research, each discipline works in their disciplinary perspectives and that in interdisciplinary research, an issue is approached from a range of disciplinary perspectives integrated to provide a systemic outcome. In transdisciplinary research, however, they affirm that the focus is on the organization of knowledge through collaboration around complex heterogeneous domains rather than the disciplines and subjects into which knowledge is commonly organized [17, 18].

Després et al. stated that the difference between interdisciplinary and transdisciplinary contributions stems from the Latin prefix "trans" which denotes transgressing the boundaries. When the transdisciplinary approach is used, the final knowledge generated is more than the sum of the collaborating

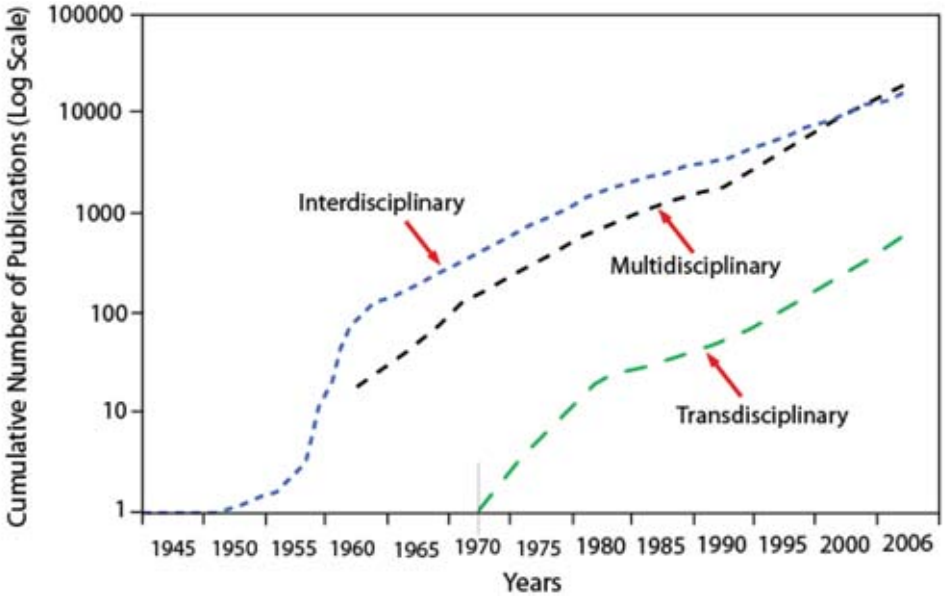

Figure 1: Web of Science Citations for Multi-, Inter- and Transdisciplinary Research.

diverse discipline components [19].

Lawrence compares interdisciplinary research approaches to a "mixing of disciplines," while transdisciplinary ones would have more to do with a "fusion of disciplines" [20]. Ramadier commented that interdisciplinarity is sufficient for the purpose of seeking coherence between different forms of knowledge produced by diverse disciplines. He also stated that interdisciplinarity plays a role in the simplification of knowledge [21].

An evaluator of interdisciplinary and transdisciplinary research also commented that "Complexity can be approached only through transdisciplinarity. ...the search for coherence in produced knowledge is not limited to the overlapping aspects of different disciplinary approaches. The non-overlapping, "marginal" aspects of each disciplinary model must also be taken into consideration and linked together. What is important is not the unity but the coherence of knowledge [21]".

After many years of researches through interdisciplinary, collaboration proves to be the most common approach, there are some issues related with interdisciplinary research. This cannot be ignored [18].

- Training Interdisciplinary Individuals: Researchers should be familiar with and open to work in other disciplines, but it takes a great deal of time and effort to fully engage another discipline, to sufficiently understand its language, concepts, substance, and methods. It is hard enough to keep up with your own discipline let alone others. Figure 1. Web of Science Citations for Multi-, Inter- and Transdisciplinary Research.
- Creating Interdisciplinary Groups: Although selecting and including researchers who have broad knowledge to work with is the starting point, creating group cohesion with smooth functioning is equally important in working teams. Researchers working together need to be committed to work crossing disciplinary boundaries. Researchers personalities are important to consider in successful interdisciplinary collaborations. There has to be a degree of mutual respect, willingness to listen, cooperation, and a commitment to work together is essential.
- Institutional Barriers to Interdisciplinarity: Even genuine attempts to foster interdisciplinarity within institutions by joint faculty appointments are difficult, because academics from different disciplines have differing expectations about what constitutes valuable knowledge generation.

Planning and organization of interdisciplinary research are also among the challenges and critical issues.

While the transdisciplinary research approach, in theory, should lead to better research progress, it

will not solve the problems and challenges mentioned above. The transdisciplinary research approach also has potential disadvantages [22]. Among them:

- The research budget will be potentially higher since the transdisciplinary research team involves a greater number of researchers;
- The effort of achieving breadth of analysis and integration may encourage superficial investigation;
- Bringing together researchers from diverse disciplines to have a collaborative team is an enormous challenge; and
- The considerable time and money required for transdisciplinary research may decrease researchers ability to assess the research outcome objectively.

Evaluation of interdisciplinary and transdisciplinary research has been discussed by many researchers [23, 24, 25, 26]. The contexts, methodologies, and conceptual framework of interdisciplinary and transdisciplinary research varies greatly. Seven generic principles have been proposed to evaluate the interdisciplinary and transdisciplinary research [23]. They are:

1. Variability of goals
2. Variability of criteria and indicators
3. Leveraging of integration
4. Interaction of social and cognitive factors in collaboration
5. Management, leadership and coaching
6. Iteration in comprehensive and transparent system
7. Effectiveness and impact

Seven generic principles mentioned above were used to develop three survey questions to compare interdisciplinary and transdisciplinary research processes. They are:

Question-1
To what extent do you think that research project organization, managing and coaching are necessary for? Please circle one (1 corresponds "Not Very" and 5 corresponds "Very").

Interdisciplinary research process

Not Very Somewhat Very

Transdisciplinary research process

Not Very Somewhat Very

Question-2
To what extent do you think that development of sustained collaboration is necessary for? Please circle one (1 corresponds "Not Very" and 5 corresponds "Very").

Interdisciplinary research process

Not Very Somewhat Very

Transdisciplinary research process

Not Very Somewhat Very

Question-3
Please rank the research processes from 1 to 5 when looking for "Quality of integrative research outcome to solve complex problems." Place a 1 next to the item that is least quality and place a 5 next to the item that has most quality.

_____Interdisciplinary research process

_____Transdisciplinary research process

4 Survey Analysis

Confidence Interval Estimation Based on the Difference in Two Means (Variance Unknown) test will be used to find out the differences between transdisciplinary and interdisciplinary research activities. Since the sample size drawn from the normal population is less than 30, the t distribution will be used to compute the confidence interval for the difference in two means, $(\mu_1 - \mu_2)$. We assume $\sigma_1^2 = \sigma_2^2 = \sigma^2$. Hence, the variance is the same within the two populations. This assumption is often made in comparing two manufacturing processes. This unknown variance, σ^2 can be estimated by using a "combined" or "pooled" estimator. The equation for pooled estimator is

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

In the analysis, typical 95 percent level of confidence with two-tailed test will be used. Therefore, a $100(1 - \alpha)$ percent two-sided confidence interval for the difference in means $(\mu_1 - \mu_2)$is given by

Table 1: Summary of Survey Responses.

Group	# in Group	Number of Responses	%	Questions Answered Partial	Questions Answered All	%
Researchers	61	28	45.9%	2	26	42.62%
Academics	75	36	48.0%	3	33	44.00%
Industry/Business	65	45	69.2%	3	42	64.60%
Graduates	49	25	51.0%	1	24	49.00%
Total	250	134	53.6%	9	125	50.00%

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

For testing the difference in two means, the test hypothesis mentioned above will be used. If the confidence interval given by Equation (2) includes $(\mu_1 - \mu_2)$, it is concluded that there is no statistical difference at a given level of confidence.

4.1 Data Analysis and Results

A survey on transdisciplinary education was conducted starting in June, 2009 for five weeks. With over 134 responses, the data provides an abundance of useful information on transdisciplinary and interdisciplinary activities. Results of the survey by groups are shown in Table 1. The survey was divided into four groups. They are researchers, academics, industry/business, and graduates. The graduates from the Transdisciplinary Masters of Engineering were also included in one of the groups in the survey. The surveys were sent to individuals from all areas of the world who had some experience or education in either interdisciplinary or transdisciplinary research and education. Some of the results were about what we expected, and only a very few of them surprised us. Response rate for the survey was better than expected. Total response rate was 53.6%, while in every category the response rate reaches to at least 45.9%.

Interdisciplinary and Transdisciplinary Research Processes Comparison (Group: Researchers): For this group survey results are given in Table 1-A in the Appendix A. Using values from this table, the pooled estimator for question-1 can be calculated as

$$\begin{aligned} S_p^2 &= \frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1+n_2-2} \\ &= \frac{(26-1)(0.74)^2 + (26-1)(0.81)^2}{26+26-2} = 0.60 \\ S_p^2 &= 0.60 \end{aligned}$$

Then,

$$S_p = 0.776$$

Two-sided confidence interval for the difference in means, $(\mu_1 - \mu_2)$ is given by

$$\begin{aligned} & (\bar{x}_1 - \bar{x}_2) - t_{\alpha/2,n_1+n_2-2} S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \\ = \; & (3.92 - 4.42) - 1.96 \times 0.776 \sqrt{\frac{1}{26} + \frac{1}{26}} \\ = \; & -0.922 \end{aligned}$$

$$\begin{aligned} & (\bar{x}_1 - \bar{x}_2) + t_{\alpha/2,n_1+n_2-2} S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \\ = \; & (3.92 - 4.42) + 1.96 \times 0.776 \sqrt{\frac{1}{26} + \frac{1}{26}} \\ = \; & -0.078 \end{aligned}$$

Rearranging yields

$$-0.922 \leq \mu_1 - \mu_2 \leq -0.078$$

Note that finding $t_{\alpha/2,n_1+n_2-2} = 1.96$ from the t distribution table, the degree of freedom is taken to be $df = 26 + 26 - 2 = 50$ and $\frac{\alpha}{2} = 0.025$. After performing same calculations for the quations #2 and #3, summary of the results are presented in Table 2.

Table 2: Summary of Calculations for Interdisciplinary and Transdisciplinary Researc Process Comparison (Group: Researchers).

Questions	S_p	$\leq(\mu_1-\mu_2)\leq$	$\bar{x}_1$	$\bar{x}_2$
#1	0.776	$-0.922\leq(\mu_1-\mu_2)\leq -0.078$	3.92	4.42
# 2	0.80	$-0.77\leq(\mu_1-\mu_2)\leq 0.095$	4.08	4.42
# 3	0.76	$-0.913\leq(\mu_1-\mu_2)\leq -0.087$	3.88	4.38

Table 3: Summary of Calculations for Interdisciplinary and Transdisciplinary Research Process Comparison (Group: Academics).

Questions	S_p	$\leq\mu_1-\mu_2\leq$	$\bar{x}_1$	$\bar{x}_2$
#1	0.87	$-0.92\leq(\mu_1-\mu_2)\leq -0.16$	4.14	4.68
# 2	0.88	$-1.32\leq(\mu_1-\mu_2)\leq -0.40$	3.68	4.54
# 3	0.81	$-1.22\leq(\mu_1-\mu_2)\leq -0.48$	3.86	4.71

Table 4: Summary of Calculations for Interdisciplinary and Transdisciplinary Research Process Comparison (Group: Business/Industry).

Questions	S_p	$\leq\mu_1-\mu_2\leq$	$\bar{x}_1$	$\bar{x}_2$
#1	0.93	$-1.02\leq(\mu_1-\mu_2)\leq -0.04$	3.79	4.32
# 2	0.83	$-1.21\leq(\mu_1-\mu_2)\leq -0.35$	3.68	4.46
# 3	0.70	$-1.27\leq(\mu_1-\mu_2)\leq -0.53$	3.71	4.61

For the researchers group, 26 sample data were analyzed. Table 2 shows that there is a statistical difference for questions 1 and 3 (confidence interval does not include $(\mu_1-\mu_2)=0$ at the 95% level of confidence in two means). By checking means of both research processes ($\bar{x}_1$ being the mean of interdisciplinary and $\bar{x}_2$ being the mean for transdisciplinary), we can conclude that the transdisciplinary research process requires better research project organization, managing and coaching than the interdisciplinary research process. Also the transdisciplinary research process provides better quality of integrative research outcome to solve complex problems than the interdisciplinary research process.

As seen from Table 2, for question 2 confidence interval includes $(\mu_1-\mu_2)=0$, therefore it is concluded that there is no statistical difference at the 95% (two sided) level of confidence in two means. It turns out that development of sustained collaboration is necessary for both transdisciplinary research process and interdisciplinary research process.

Using randomly selected 28 samples, similar survey analysis were performed for academics, industry/business, and graduates groups and the results of analysis are shown in Tables 3, 4 and 5.

By reviewing Tables 3, 4 and 5 we conclude that outcome of the survey results from academics, business/industry, and graduates turn out to be exactly same. In other words;

- Research project organization, managing, coaching, and development of sustained collaboration are more needed for the transdisciplinary

Table 5: Summary of Calculations for Interdisciplinary and Transdisciplinary Research Process Comparison (Group: Graduates).

Questions	S_p	$\leq \mu_1 - \mu_2 \leq$	$\overline{x}_1$	$\overline{x}_2$
#1	0.79	$-1.19 \leq (\mu_1 - \mu_2) \leq -0.31$	3.88	4.63
# 2	0.65	$-1.94 \leq (\mu_1 - \mu_2) \leq -0.43$	3.79	4.58
# 3	0.81	$-1.20 \leq (\mu_1 - \mu_2) \leq -0.30$	3.75	4.50

research process than the interdisciplinary research process.

- Development of sustained collaboration is necessary for the transdisciplinary research process more than the interdisciplinary research process.
- Transdisciplinary research process does provide better quality research outcome than the interdisciplinary research process.

5 Conclusions

Over the last six decades the integration of research methods and techniques across the disciplines has changed rapidly. The numbers of disciplines, subdisciplines, and fields of study have grown from less than twenty-five to well over eight thousand and are still growing rapidly. 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.

The growth in disciplines and subdisciplines drives the need to be able to have several disciplines often working on solving complex problems or issues. This has led to the creation of intradisciplinary, multidisciplinary, interdisciplinary and transdisciplinary as methods of working with these problems and issues. All of these have improved the process to a higher level but still may run into issues with the large scale complex problems.

We are searching for an answer in this chapter; *is transdisciplinary research process better than interdisciplinary research process in solving complex problems?* Three questions used in the survey were used to produce the results to this question. The survey results gave us in two of the three questions the result that transdisciplinary research was the better choice. Question one had agreement of all four groups in finding that in research project organization, managing, coaching, and the development of sustained collaboration are more needed for the transdisciplinary research process than the interdisciplinary research process.

Question two found agreement in three of the four groups in the development of sustained collaboration being necessary for the transdisciplinary research process more than the interdisciplinary research process. The group of researchers felt that both the interdisciplinary and transdisciplinary processes required the development of sustained collaboration. Question three found agreement in all four groups that the transdisciplinary research process does provide better quality research outcome than the interdisciplinary research process.

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Dr.Tom Kollman retired in 2004 after forty years with the U.S. Air Force, E-Systems, Inc. and Raytheon. In 22 years in the Air Force the last 14 years were operating and managing F-111 simulator facilities in the U.S. and England. Dr. Kollman earned a B.S. in industrial technology from Southern Illinois University-Carbondale and a M.S. degree in human resources, management and development from Chapman University. Retiring from the Air Force, Dr. Kollman joined E-Systems in 1986 as an engineering trainer. E-Systems merged with Raytheon in 1995. During the time with Raytheon, Dr. Kollman developed an efficient active training department doubling the training available to the employees. He received a CAGS certificate in 1995, in adult and continuing education with Virginia Tech University. In 1998, a Masters Equivalent Certificate for continuing engineering studies in systems and software from the University of Texas at Austin and a M.E. in transdisciplinary design, process and systems from Texas Tech University in 2000. Dr. Kollman retired in 2004 as the training manager for Raytheon IIS. He has taught undergrad and graduate school since 1992 for Averett College, Texas Tech University and Texas A & M University-Commerce, teaching numerous subjects covering business, management, systems engineering, transdisciplinary design, process and systems, computer science and information. He has authored and presented several papers at conferences and workshops in the United States, Turkey and Korea. Dr. Kollman graduated with a Ph.D. in Mechanical Engineering with a transdisciplinary design, process and systems concentration from Texas Tech University in 2010 and plans to continue the enjoyment of teaching undergraduate and graduate students for many more years.

Dr. Atila Ertas is a Professor of Mechanical Engineering and Director of Transdisciplinary Ph.D. Program on Design, Process and Systems. Ertas is author/co-author of four books and co-editor of more than 35 proceedings. He has been teaching capstone design classes for more than 25 years. He is a Senior Research Fellow of the IC^2 Institute at the University of Texas Austin, a Fellow of American Society of Mechanical Engineers(ASME), a Fellow of Society for Design and Process Science (SDPS) and a Fellow and honorary member of The Academy of Transdisciplinary Learning & Advanced Studies (TheATLAS). He is also an honorary member of International Center for Transdisciplinary Research (CIRET), France. He has published over 150 scientific papers that cover many engineering technical fields. He has been PI or Co-PI on over 40 funded research projects. Under his supervision more than 170 MS and Ph.D. graduate students have received degrees.

APPENDIX - A

Table 1-A

Question #1

# of Sample	A	B
1	3	4
2	3	3
3	3	5
4	4	4
5	3	5
6	5	5
7	4	5
8	5	5
9	4	4
10	5	3
11	3	2
12	4	4
13	4	5
14	4	5
15	4	4
16	4	5
17	5	5
18	3	5
19	5	5
20	3	5
21	4	5
22	5	5
23	4	4
24	4	4
25	3	5
26	4	4
SUM	*102*	*115*
SQUARE	*414*	*525*
MEAN	*3.92*	*4.42*
SD	*0.74*	*0.81*
SD ERROR	0.15	0.16

Question #2

# of Sample	A	B
1	4	5
2	4	4
3	2	5
4	5	5
5	3	5
6	5	5
7	4	4
8	4	4
9	4	4
10	5	4
11	3	4
12	4	5
13	3	4
14	4	5
15	4	4
16	5	5
17	5	5
18	3	5
19	3	5
20	4	5
21	4	4
22	4	5
23	4	4
24	4	4
25	3	3
26	4	2
SUM	*101*	*114*
SQUARE	*407*	*514*
MEAN	*3.88*	*4.38*
SD	*0.77*	*0.75*
SD ERROR	0.15	0.15

Question #3

# of Sample	A	B
1	3	4
2	4	4
3	3	5
4	4	4
5	4	5
6	5	5
7	5	5
8	5	5
9	4	5
10	3	5
11	3	3
12	5	5
13	4	4
14	5	5
15	4	4
16	4	5
17	5	5
18	2	2
19	5	5
20	4	5
21	4	5
22	5	5
23	4	4
24	4	4
25	4	4
26	4	3
SUM	*106*	*115*
SQUARE	*448*	*525*
MEAN	*4.08*	*4.42*
SD	*0.80*	*0.81*
SD ERROR	0.16	0.16