

SURVEY AND FRAMEWORK FOR TRANSDISCIPLINARY
RESEARCH ACTIVITIES

by

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ABSTRACT

The integrating of research methods and techniques across disciplines for many years has been of great interest in the humanities, social sciences, and natural sciences dating back to the 1950's. A given area of study is called a discipline provided it has cohesive tools, specific techniques and methods, and a well-developed disciplinary terminology. There is a need to allow these disciplines to work and solve complex problems in coordination with each other.

During the researching of many technical papers, one described the growth explosion in knowledge fields (8500), disciplines and sub-disciplines (over 4000). In nearly all the papers it was also noted there is little mention of the engineering disciplines in relation to the humanities, natural sciences and social sciences even though all these disciplines have worked together for years.

The purpose of this study was to collect views and assess the level of satisfaction of researchers and educators with respect to transdisciplinary activities through survey; and to also develop a new transdisciplinary research process based on the system of systems approach to solve complex problems that face civilization.

The details of the survey instrument utilized in this research are to define the objectives of the survey process. Decide on the target audience and sample size. Create relevant questions for three target groups on transdisciplinary research, transdisciplinary education and to compare interdisciplinary and transdisciplinary research processes. Conduct a pilot test and then modify and finalize the questions. Collect, compile the data and analyze the data using statistical and relationship analysis.

The results of the statistical and relationship checks have reinforced our belief that the more complex the systems, issues, or problems become the more there is a need for a framework capable of guiding the effort through the maze to a successful solution. The

new concept for transdisciplinary research process based on the system of systems approach to solve complex problems has been developed.

This research has determined the need for a good framework to be used with transdisciplinary research. The research we gained in producing and conducting the survey gave a viable and positive return through the responses of the participants. This has convinced us that we will continue forward with the Transdisciplinary Research Process (TD-RP) based on expanding the System of Systems (SoS) framework.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Integrating research methods and techniques across disciplines for many years has been of great interest in the social and natural sciences dating back to the 1950s [1].

A particular area of study is called a discipline provided it has cohesive tools, specific techniques, 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 the various disciplines working essentially independently, each from their 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 the *interdisciplinary* activities researchers from different disciplines work jointly but from respective disciplinary perspectives. Interdisciplinary research concerns the transfer or exchange of techniques and methods between disciplines. This interdisciplinary research was considered in the following three degrees [2].

1. A degree of application: when the methods of nuclear physics were transferred to medicine, it led to the appearance of new treatments for cancer.
2. A degree of epistemology: when the transfer of methods of formal logic to the area of general law generated some interesting analyses of the epistemology of law.
3. A degree of generation of new disciplines: when methods from mathematics were transferred to physics, the discipline of mathematical physics was generated, and when they were transferred to meteorological phenomena and stock market processes, they generated chaos theory.

Both multidisciplinary and interdisciplinary activities overflow discipline boundaries, but their goal remains within the framework of disciplinary research. Neither multidisciplinary nor interdisciplinary approaches provide an environment which can promote the collaboration and synthesis necessary to extend beyond artificial disciplinary boundaries, nor produce truly creative and innovative solutions to multidimensional, complex problems. During the past two decades, there has been an explosion of complex problems facing engineers and a rapid evolution of the technical understanding in science and engineering necessary to attack these problems.

A few examples are the groundbreaking advancements in semi-conductor and software technologies, bio-sciences, and nanotechnology. These advancements include not only the design or redesign of engineering systems with numerous components and subsystems interacting in multiple and intricate ways. Further, these systems are likely to be both dynamic and adaptive in nature. Solutions to such large-scale, complex problems require many activities which cross discipline boundaries. Nobel Laureate Herbert Simon states: [3]

“...Today, complexity is a word that is much in fashion. We have learned very well that many of the systems that we are trying to deal with in our contemporary science and engineering are very complex indeed. They are so complex that it is not obvious that the powerful tricks and procedures that served us for four centuries or more in the development of modern science and engineering will enable us to understand and deal with them. We are learning that we need a science of complex systems, and we are beginning to construct it...”

1.2 Need and Motivation

In German-speaking countries the term 'transdisciplinarity' is often used for integrative forms of research. Stokols (1998) defined transdisciplinarity as a process by which the researchers work jointly using a shared conceptual framework that draws together discipline-specific theories, concepts and approaches to address a common problem [4].

A truly transdisciplinary research and educational system is needed to address large-scale, complex problems and to prepare the researchers and designers of the future. The four critical attributes of this new system are listed below.

- 1) The development of a more comprehensive understanding of large scale problems
- 2) The clarification of theoretical issues involved in crossing discipline boundaries
- 3) The integration of concepts and methods from neighboring disciplines which share similar levels of analysis. For example, the fields of pharmacology, brain imaging, and neuroscience share a bio-behavioral perspective (focusing on.)
- 4) The development of methods of understanding to adapt and incorporate designs into existing natural and societal systems in order to reach harmonic and mutually beneficial conditions. (Example: We efficiently design and build millions of automobiles only to have them stopped in massive traffic jams each day; wasting millions of people's time, costing billions each year while polluting the atmosphere. This is a direct result of isolated discipline-oriented design.)

The growing interconnections among academic disciplines, combined with the explosion of knowledge have transcended the discipline-specific academic fields. It is time to reorganize scholarly interests within the university. Educational programs must explicitly step beyond the discipline-based approach to learning and focus on knowledge domains that cut across traditional academic fields - the transdisciplinary approach to teaching and research. It is time to think about the university as a place of ideas, not as an organization of academic disciplines [5].

During the past decade, transdisciplinarity and related research topics have become the focus of important scientific contributions. Recently, innovative research strategies and methods tackling complex problems have been presented by many researchers and educators. The results of transdisciplinary research and education are the emphasis of teamwork and the bringing together of multiple distinct investigators, methodologies or disciplines to create new, fresh, invigorating ideas that expand the boundaries of what has been done before. The transdisciplinary approach develops in people the desire to seek

collaboration outside the limits of their discipline to explore different perspectives and new possibilities.

1.3 Research Objectives

The objectives of this research work are:

- To collect the views and assess the level of satisfaction of the researchers and educators with respect to transdisciplinary activities through survey
- To develop a new transdisciplinary design process based on the system of systems approach to solve complex problems that face civilization

1.4 Contributions

It is noteworthy to observe that engineering has not been included extensively as a part of the transdisciplinary research process in more than one hundred scientific research papers reviewed. This research work undertakes the challenge of applying a System of Systems (SoS) [6] approach to develop a new transdisciplinary framework or process which includes engineering discipline for the solution of global complex problems.

The primary intent of this research was to understand and assess the importance of transdisciplinary research and education through survey. To the best knowledge of the author of this dissertation, no previous or similar surveys have been conducted by other researchers on this topic. In particular, having the view of different groups of people from research institutes, business, industry and academia on transdisciplinary activities has been a rich source of information that will help the researchers and educators better understand key problems of transdisciplinary activities.

CHAPTER 2

DISCIPLINARY APPROACH

2.1 Discipline Defined

In the original sense, *discipline* refers to the systematic instruction given to a disciple [7]. This sense also preserves the Latin origin of the word, *disciplina* “instruction”, from the root *discere* “**to learn**,” and from which *discipulus* “**disciple, pupil**” also derives [8].

“Discipline” Function: 1: punishment 2: *obsolete*: **Instruction** 3: **a field of study** 4: **training that corrects, molds, or perfects the mental faculties or moral character** 5a: control gained by enforcing obedience or order 5b: orderly or prescribed conduct or pattern of behavior 5c: **Self-Control** 6: **a rule or system of rules governing conduct or activity**.

A particular field of study is called a discipline provided it has cohesive tools, specific techniques, methods, and a well–developed disciplinary terminology. Disciplines inevitably develop into self–contained shells; interaction with other disciplines is often minimized. Because of the rise in new technological and scientific discoveries and products, the disciplines have multiplied rapidly over the last five hundred years 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 [9]. 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.

To be disciplined is subject to context. It can be a virtue, meaning the ability to follow instructions well, or it can be a euphemism for punishment, which may be referred to as a disciplinary procedure. As a noun, discipline refers to an instrument of punishment.

Self-discipline refers to the training that one gives one's self to accomplish a certain task or adopt a pattern of behavior, even though one would rather be doing something else. Thus, self-discipline is the assertion of will power over more basic desires. This is often called "self-control". Self-discipline is to some extent used often as a substitute for motivation; this occurs when a person uses reason to determine the best course of action that opposes the individual's desire [10].

In 1990, Peter Senge wrote a book titled, *The Fifth Discipline: the Art and Practice of the Learning Organization* [11]. The five disciplines covered are systems thinking, personal mastery, mental models, shared vision, and team learning. The first three have particular application for the individual participant and the last two are for group application. Senge tells us that: "These disciplines might just as well be called the leadership disciplines as the learning disciplines. Those who excel in these areas will be the natural leaders of learning organizations." Systems' thinking possesses the distinction of being the "fifth discipline", since it serves to make the results of the other disciplines work together for the organization and/or business benefit.

2.2 Disciplinary

The following highlighted items for disciplinary are considered to be important for use in this dissertation. 1a: of or relating to discipline 1b: designed to correct or punish breaches of discipline 2: of or relating to a particular field of study [12] Disciplinary, *adj.*, disciplinarity, *n.*, is a term used to describe types of knowledge, expertise, skills, people, projects, communities, problems, challenges, studies, inquiry, approaches, and research areas that are strongly associated with academic fields of study (academic disciplines) or areas of professional practice (professions).

An excellent example of academic disciplinary specialization is found at the web site for The Carnegie Foundation for the Advancement of Teaching [13]. Founded by Andrew Carnegie in 1905 and chartered in 1906 by an Act of Congress, The Carnegie Foundation for the Advancement of Teaching is an independent policy and research center whose

charge is “to do and perform all things necessary to encourage, uphold, and dignify the profession of the teacher.”

The improvement of teaching and learning is central to all of the Foundation’s work. As we bring together researchers, teachers, policymakers and members of organizations with common interests in education, we work to invent new knowledge and to develop tools and ideas that allow us to foster positive change and enhanced learning in our nation’s schools.

An example of this is Educating Engineers-Designing for the Future of the Field, S.D. Sheppard, et al. [14]

Most academic disciplines have a similar society or organization that is a knowledge support center for that discipline. Three examples of this are the American Society of Mechanical Engineers (ASME), the Institute of Electrical and Electronics Engineers, Inc. (IEEE), and the International Council on Systems Engineering (INCOSE). These organizations are excellent examples of true academic disciplinary groups for their specific discipline.

2.2.1 Disciplinary Research

Disciplines are constituted by defined academic research methods and objects of study. They include frames of reference, methodological approaches, topics, theoretical canons and technologies. Disciplines can also be seen as ‘sub cultures’ with their own language, concepts, tools and credentialed practitioners (pg. 596) [15, 16].

2.2.2 Disciplinary Studies

Disciplinary studies are projects that take place within the bounds of a single, currently recognized academic discipline [17, 18].

2.2.3 Monodisciplinary

Mono means one. This approach to practice, research and leadership means only one discipline is brought forward to solve the problem or issue. People working in one discipline such as agriculture, sociology, economics, law, or engineering study the same research objects, share the same paradigms (world view and set of assumptions about what is real), use common methodologies, and speak the same language and terminology [19, 20].

Two examples of organizations related to monodisciplinarity are the Society for Neuroscience, (SfN) [21] and the Federation of European Neuroscience Societies, (FENS) [22].

SfN is a nonprofit membership organization of scientists and physicians who study the brain and nervous system [21]. Since its inception in 1969, the Society has grown from 500 members to over 38,000. Today, SfN is the world's largest organization of scientists and physicians devoted to advancing the understanding of the brain and nervous systems. The second organization is the Federation of European Neuroscience Societies, (FENS) [22]. FENS is the European partner of the American Society for Neuroscience. It represents a large number of European neuroscience societies and several monodisciplinary societies and was founded in 1998 at the Forum of European Neuroscience in Berlin. FENS, the successor organization of ENA, the European Neuroscience Association has a governing council formed by representatives of all member societies.

A possible drawback to the monodisciplinary approach is that experience has demonstrated that the greatest gains and improvements in process often come from the interaction of multidisciplinary rather than a single disciplinary approach [23].

2.2.4 Unidisciplinary

A large body of work in gerontology and geriatrics addresses the concept of teamwork and disciplinary working relationships. The first model to be described is listed as a unidisciplinary model. In this model, the roles of the clinicians are segregated along

professional boundaries. The clinician who is providing care to older clients' functions independently, sometimes being unaware that other professionals are involved in the case [24]. Limited inter-professional communication, independent rather than collaborative goal-setting, and minimal optimization of healthcare resources, among other features, are characteristic of this model. This is not the best choice for the patient or for other healthcare givers. Another definition of unidisciplinary teams describes the makeup of many providers from a single background, such as a group of public health nurses providing home care [25]. All team members share the same professional skills and training, speak a common language of healthcare, and function in the same role within the group. This form is often seen in visiting public healthcare situations.

Four examples taken from Gary Direnfeld's paper covering team models of healthcare situations are given in chapters two and three [26]. It should be noted that these team models arise primarily from the health and mental health communities where the inputs of multiple disciplines are aimed at facilitating resolution of health or mental health concerns. Over the course of the last 40 years, it has been determined that the degree by which the inputs are coordinated with other inputs will drive the output, service delivered. This must be as concise and inclusive as possible, to assure the best results are achieved for the recipient of the service.

Four team models evolved over the years in the health and mental health literature. The four models arise depending on (a) if other professionals are invited to participate and (b) how these other professionals are then organized to participate once invited. The four team models are unidisciplinary, multidisciplinary, interdisciplinary shown in chapter two and transdisciplinary shown in chapter three.

The unidisciplinary team applied to collaborative family practice has as its core members, two lawyers and the respective clients. It is best depicted in the following graphic figure:

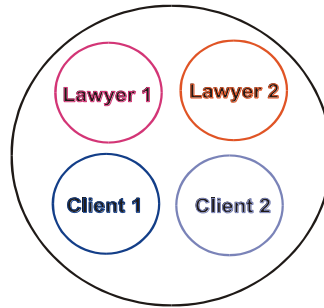


Figure 2.1 Unidisciplinary

2.2.5 Intradisciplinary

The intradisciplinary movement created some conflict that had the potential to be a serious problem for healthcare administrators. The overriding cause of the conflict among nurses stemmed from their major knowledge assessing modes: empirical, noetic, and rational. Each individual has a predisposition to use a particular style or a combination of the three. Meeth [27] proposed a hierarchical classification that at the bottom of the hierarchy was intradisciplinary studies, i.e., studies composed of a single discipline. Regeer [28] asserts that while single disciplinary work has its place, it is limiting when trying to solve complex societal problems, because only one lens is brought to bear on the dynamics inherent in the complexity. Ertas [29], among others, refers to the idea of intradisciplinary communication, a form of well-developed, exclusionary disciplinary jargon that precludes any permanent bridges between disciplines. Indeed, Wallerstein [30] noted that individual “disciplines are organized like corporate structures in the form of university departments, programmes of instructions, degrees, scholarly journals, national and international associations, and even library classifications.” Bevan [31] suggests that scholars in different, separate disciplines are in competition with each other for funding and for intellectual space where they can express their ideas while confined within their disciplinary boundaries.

2.3 Multidisciplinary

The methodology or compound discipline refers to knowledge composed of or combining several usually separate technical branches of learning or fields of expertise [32, 33]. In academia, pedagogy, physical sciences, earth sciences, human sciences, and social sciences in general are interdisciplinary. Interdisciplinary is a term of art in the teaching professions, whereas the term multidisciplinary has become the hallmark of many modern technical professions. The first approach that comes to mind is the multidisciplinary activities involving researchers from various disciplines working essentially independently, each from his/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.

2.3.1 Multidisciplinary Research

Multidisciplinary research occurs when a range of different disciplines are assembled for a research task. Different disciplines come together, (typically to deal with a complex or ‘real world’ problem) but with each group working primarily within its own framings and methods. The disciplines co-exist in a defined context while retaining their own specific boundaries and identities [34]. This is a research approach that assembles rather than combines separate disciplinary perspectives, adding a breadth of knowledge, information and methods. Work is done independently following separate perspectives [35, 36]. See figure 2.2:

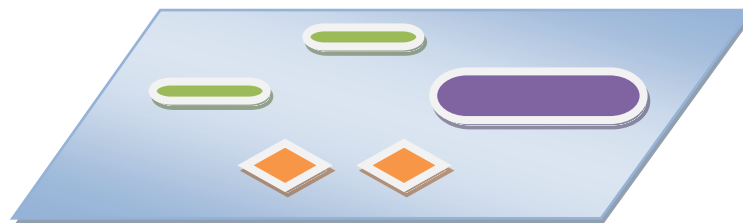


Figure 2.2 Multidisciplinary

The multidisciplinary model Figure 2.3 has been referred to by some collaborative family practitioners as the ‘referral model’, where the lawyers refer out to family or financial professionals [37]. Here, the clients go and meet with the respective professionals and their input is brought back to the 4-way meetings between lawyers and clients, by way of written report or verbal conveyance through either the lawyers or the clients. The family and financial professionals thus provide information from a distance to the core team. This model is best depicted with the following graphic figure 2.3:

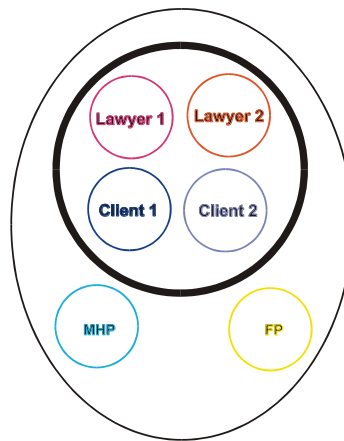


Figure 2.3 Multidisciplinary “Referral Model”

2.3.2 Cross-Disciplinary

Cross-Disciplinary [38] is defined as involving **two or more academic disciplines**; interdisciplinary; cross-disciplinary studies.

The University of Pennsylvania Law School offers a cross-disciplinary approach to legal education [39]. It is clear that global leaders in the law must be well-trained in the disciplines related to law. This training is infused into the curriculum and is augmented by the ability of students to take courses at any of the graduate and professional schools at the University of Pennsylvania, one of the premier Ivy League schools.

‘Michael A. Fitts, Dean and Bernard G. Segal Professor of Law’, was quoted:

“There is not a more exciting moment in our nation’s history than to be involved in the legal education today. Virtually every fundamental issue facing our country is illuminated through the critical thinking developed in traditional and cross-disciplinary legal training.”

Another university offering a Cross-Disciplinary degree program is NOVA Southeastern University’s Graduate School of Humanities and Social Sciences offers a Master of Arts degree in Cross-Disciplinary Studies [40]. This is multidisciplinary, experiential, and allows students to self-design their graduate studies. The program is designed to meet the needs of students who are seeking a broader learning forum and who appreciate the unique self-design of cross-disciplinary studies.

2.4 Interdisciplinary

Interdisciplinary is defined in the following two ways and many of us can relate to both definitions [41].

Interdisciplinary is the combining or involvement of two or more academic disciplines or fields of study: Interdisciplinary is the combining of two or more professions, technologies, departments, as in business or industry.

As described above in 2.3 multidisciplinary;[32] in academia, pedagogy, physical sciences, earth sciences, human sciences, and social sciences in general are known as interdisciplinary fields, this is a term of art in the teaching professions.

Using our study of gerontology and geriatric healthcare as an example of interdisciplinary team work, clinicians from different professions assume roles and carry out responsibilities that share common goals for their clients [42]. Roles often overlap and may be flexible over time. Interdisciplinary team members understand the educational background, know the areas of expertise of their team members, and are also aware of the

roles assumed by each member's profession. As a team they plan and implement the tasks undertaken in an integrated manner. They communicate frequently and plan and undertake roles according to level of competence rather than according to professional traditions. Implementation in this form of mutually agreed-upon goals during treatments often yields results greater than those accomplished by separate profession-specific approaches.

The University of Pennsylvania has demonstrated an outstanding selection of interdisciplinary education within its schools providing opportunities for undergraduate, graduate and continuing education [43]. Penn currently ranks as one of the premier research universities in the nation with more than \$700 million in annual R & D expenditures. The broad-based approach is multidisciplinary, with collaborations taking place between faculty and students from across all of the 12 schools.

2.4.1 Interdisciplinary Research

'Interdisciplinary research' (See Fig.2.4 below) refers to a range of approaches from the simple communication of ideas to mutual integration of organizing concepts, methodology, epistemology etc [44, 45]. Rather than disciplines operating in parallel, it involves a synthesis of knowledge. In which understandings change in response to the perspectives of others. The aim is to seek coherence between the knowledge's produced by different disciplines [46].

The US National Academy of Sciences definition for interdisciplinary is "a mode of research that integrates information, data, techniques, tools, perspectives, concepts and /or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice" [47, 48].

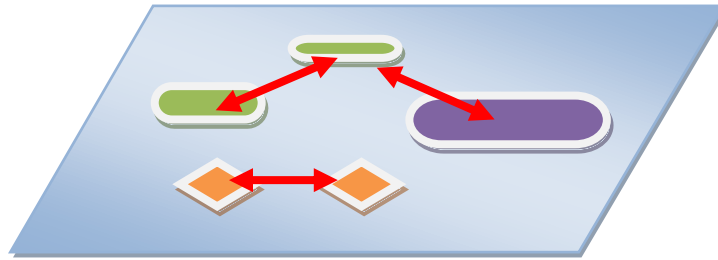


Figure 2.4 Interdisciplinary

2.4.2 Interdisciplinary Studies

The interdisciplinary studies consist of several unrelated academic disciplines. These disciplines have contrasting research paradigms such as differences in qualitative and quantitative approaches or different analytical and interpretative approaches. Because of these differences they are forced to cross subject boundaries to create new knowledge and theory and solve a common research goal [49, 50].

Julie Thompson Klein [51] speaking at the 2004 Fenner Conference on the Environment in Canberra, AU, described how the:

“Interdisciplinary approaches integrate separate disciplinary data, methods, tools, concepts, and theories in order to create the holistic view of common understanding of a complex issue, question, or problem. The “instrumental”, “strategic”, “pragmatic” or “opportunistic” forms focus on economic, technological, and scientific problem-solving differ from critical and reflexive forms that interrogate the existing structure of knowledge and education. Theories of interdisciplinarity that are premised on unity of knowledge differ from a complex, dynamic web or system of relations. Scope also differs. “Narrow interdisciplinarity” involves disciplines with more or less the same paradigms and methods. In “broad interdisciplinarity”, they differ”.

Collaborative law and/or collaborative practice offer innovative approaches as an alternative resolution process [52]. The key to this process is having parties in conflict

being aided by lawyers with a non-adversarial approach to resolve the issues in both the long and the short term interests of the parties. This removes the threat of litigation: all the parties must agree that the respective lawyers cannot be used in a litigation process and must also agree to disqualify themselves in the event the collaborative process cannot be honored. This is called the sine qua non of the collaborative approach.

In the interdisciplinary model of Direnfeld's "*Understanding collaborative team models*", the model builds on the multidisciplinary where the respective outside family or financial professionals are invited to have a seat at the negotiation table to share their inputs directly and stand available to discuss matters relative to their insights and data. Here the data is delivered directly and increases the integrity that the data is unaltered. As a result, the data is also not subject to misinterpretation, and by virtue of the professionals' availability at the table, they can speak immediately to issues or points of clarification and/or aid in the development of creative solutions. This model is best depicted with the Figure 2.5 below:

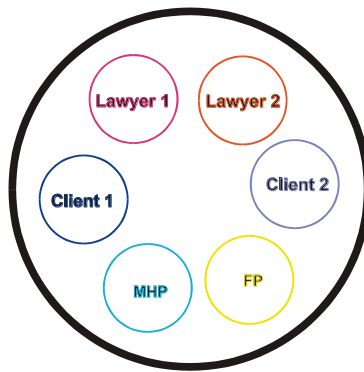


Figure 2.5 Interdisciplinary

2.5 Example Case Study

Wind power promises a clean and free source of electricity. It promises to reduce our dependence on imported fossil fuels and to also reduce the output of greenhouse gases. Many countries are, therefore, promoting the construction of vast wind 'farms' and

encouraging private companies with generous subsidies. The U.S. Department of Energy (DOE) goal is to see 5 percent of our electricity produced by wind turbine farms in 2010. The history of wind power shows a general evolution from the use of simple, light devices to heavy, material-intensive drag devices and finally to the increased use of light, material-efficient aerodynamic lift devices in the modern era.

During the winter of 1887-88, Charles F. Brush built the first automatically operating wind turbine for electricity generation [53]. It was the world's largest wind turbine with a rotor diameter of 17 m (50 ft.) and 144 rotor blades made of cedar wood. The turbine ran for 20 years and charged the batteries in the cellar of Brush's mansion.

The wind has been an important source of energy in the U.S. for some time. Over 8 million mechanical windmills have been installed in the United States since the 1860s [53]. It is interesting to note that some of these units have been in operation for more than a hundred years.

A wind turbine system design consists of sub-systems to catch the wind's energy, point the turbine into the wind, convert mechanical rotation into electrical power, and systems to start, stop, and control the turbine. To design today's impressive and giant wind turbine structures, many researchers from different disciplines collaborate and work together. Among them, mechanical engineers work on gear design, civil engineers work on structure design, material engineers work on the most suitable material selection for the application, electric engineers work on power transmission and control system design, and finally, wind engineers work on rotor blade design, etc. A simple methodology could be to create a collaborative research team to design wind turbines efficiently. Of course, the collaborative effort can be organized many different ways.

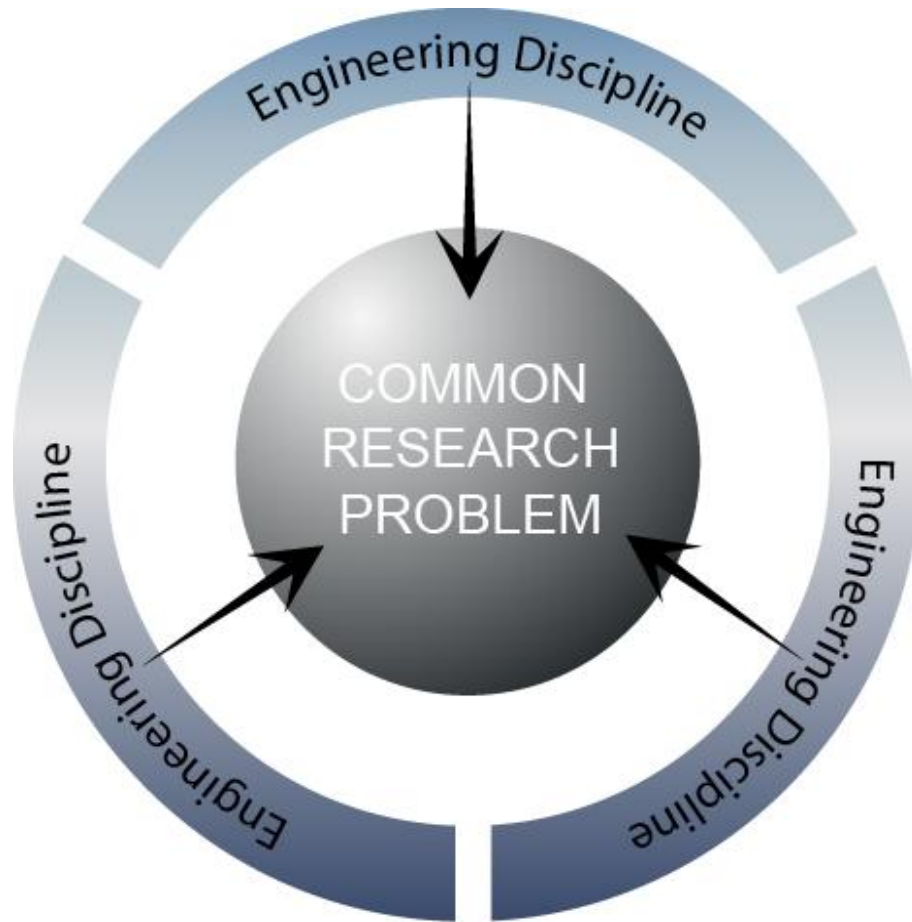


Figure 2.6 Multidisciplinary Research Process

Assume that engineers from diverse disciplines attempt to design a wind turbine. As shown above in Figure 2.6, the common research problem is to design a wind turbine. A multidisciplinary community or project is made up of people from more than one discipline and/or profession who are engaged in working together as equal stakeholders in addressing a common challenge. The key question is how well the challenge can be decomposed into neatly separable sub-parts, and then addressed via the distributed knowledge in the community or project team. The lack of shared vocabulary between people and the communication problem is an additional challenge in these communities and projects. However, if similar challenges of a particular type need to be repeatedly addressed, and each challenge can be properly decomposed, a multidisciplinary community can be exceptionally efficient and effective.

Once the work or research is done, everyone goes back to their respective place [55], [56], [57]. Even if people simply mingle disciplines to problem-solve, with each discipline maintaining its distinctiveness, they remain multidisciplinary [58].

People from respective disciplines retain their independence, temporarily taking direction from a team leader. This leader is the person who sets the goal(s) of the team's work. A multidisciplinary person is a person with degrees from two or more academic disciplines, so one person can take the place of two or more people in a multidisciplinary community or project team [59]. Brown adds a further clarification that if people engage in multidisciplinary studies, they simultaneously take courses from many different disciplines, but do not attempt to integrate them in any way [60]. Over time, the multidisciplinary work does not typically lead to an increase or a decrease in the number of academic disciplines.

If we go back to our earlier example of the gerontology clinicians' interdisciplinary model of team work, it means that clinicians from several different professions are involved in the delivery of the care. As in the unidisciplinary model, the roles and responsibilities of each practitioner remain segregated by profession [61]. Team members may know the educational background and traditional roles of one another and possess general knowledge of the scope of practice of each profession represented on the team. Information sharing and joint planning on approaches to care may occur. However, shared goal-setting and collaboration on patient-related tasks are not characteristic of this model.

Goals and tasks are developed and implemented independently according to recognized professional boundaries. Multidisciplinary teams address separately each problem of the older adult [62]. Regrettably, integration of services and care goals is not a feature of this approach.

Interdisciplinary Research Concept: In *interdisciplinary* activities, researchers from different disciplines work jointly on common problems by exchanging methods, tools, and concepts among them to find integrated solutions.

If the research approach is interdisciplinary, as shown in Figure 2.7, researchers from different disciplines start communicating and collaborating with each other to optimize their sub-component design considering the whole system design requirements. Once the compatibility and reliability of the sub-components are ensured, then they are delivered for assembly of the system. This provides an integrated solution to a common problem.

As mentioned previously, mechanical engineers work on gear design, civil engineers work on structure design, material engineers work on most suitable material selection for the application, and electric engineers work on power transmission and control system design. Finally, wind engineers work on rotor blade design and deliver their sub-product design independently. The whole system can then be assembled. The question is: Is this process providing an optimum design? The answer is obvious: No. Better collaboration and organization is necessary for this kind of complex art affect design.

Although wind power promises a clean and free source of electricity, it can raise environmental and community concerns. For example:

- noise and vibrations caused by wind turbines may cause sleep disruptions and other health problems among people who live nearby
- they can be visually intrusive for residents living near them
- they can disturb wildlife habitats and cause injury or death to birds
- turbulence from wind farms could adversely affect the growth of crops in the surrounding countryside
- they may pose significant threats to migrating birds
- having huge wind turbines, each standing taller than a 60-story building and having blades more than 300 feet long may disturb the community residence

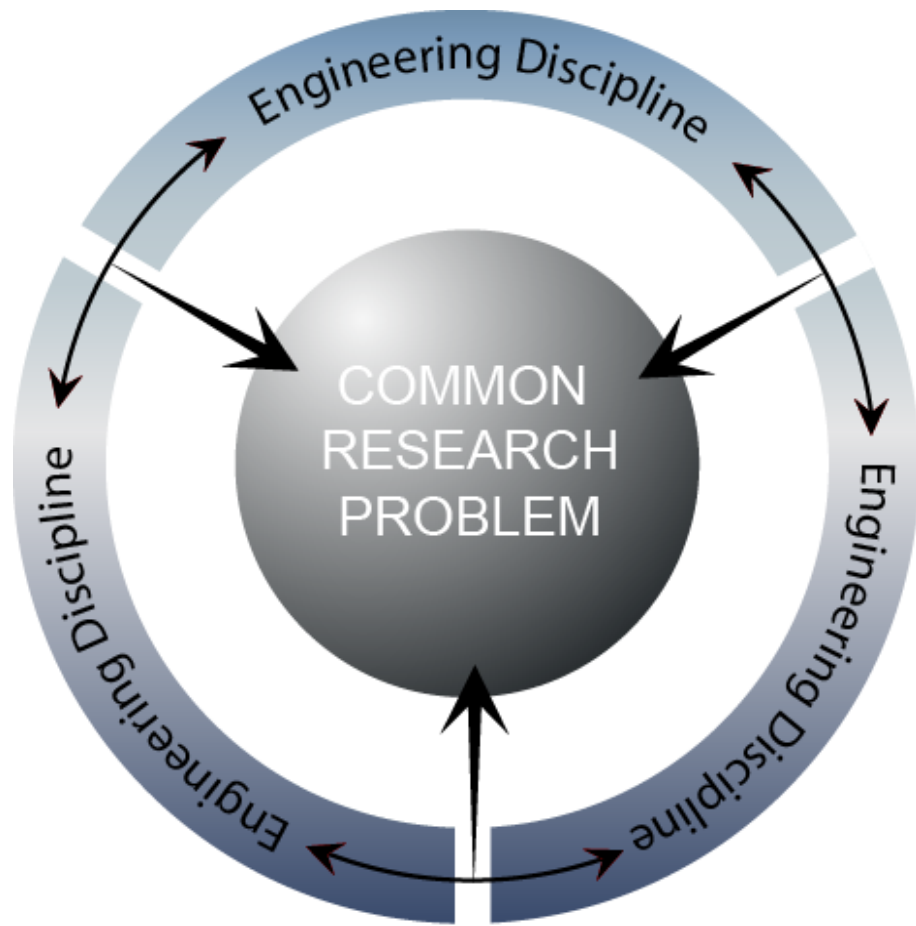


Figure 2.7 Interdisciplinary Research Process

In the late 1980s, the California Energy Commission reported 1,300 birds were killed by wind turbines, including over 100 golden eagles at Altamont Pass, CA. Environmental issues related to wind turbines include: impacts on wildlife, habitat, wetlands, dunes, and other sensitive areas such as water resources, soil erosion and sedimentation. There are many other areas of strong concern. They are: interference with TV reception, microwave reception interference, depreciating property values, increased traffic, road damage, cattle being frightened from rotating shadows cascading from the blades in a setting sun, rotating shadows in nearby homes, concerns about stray voltage, concerns about increased lightning strikes and many others. Currently, all of these issues are being raised in states where wind farms have been introduced.

CHAPTER 3

A NEW APPROACH: TRANSDISCIPLINARITY BACKGROUND

3.1 Introduction

In the German-speaking countries the term *transdisciplinarity* is used for integrative forms of research [63]. Transdisciplinary education and research 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. This shared framework utilizes discipline-specific theories, concepts, and methods to address common problems. 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 [64]. The scope and creative potential of cross-disciplinary research increases as one moves from interdisciplinary to transdisciplinary approaches [65].

From the discussion at the end of Chapter 2, we begin to realize that wind turbine design, operation, and maintenance is not a simple task but extremely complex. It involves not only engineers but also researchers from social science, natural science, and humanities. This research process is called the transdisciplinary research process.

3.2 Transdisciplinary Concept

As shown below in Figure 3.1, this process involves not only crossing engineering disciplinary boundaries but also requires crossing families of disciplinary boundaries (engineering, social science, natural science, and humanities) [66]. For example, researchers from environmental science should undertake an environmental assessment of the site and a comprehensive consultation exercise with local community and environmental bodies in terms of development of the wind turbine farms. Engineers

should work with researchers from social science, natural science, and humanities to understand the impact on environment and community people to reiterate their design.

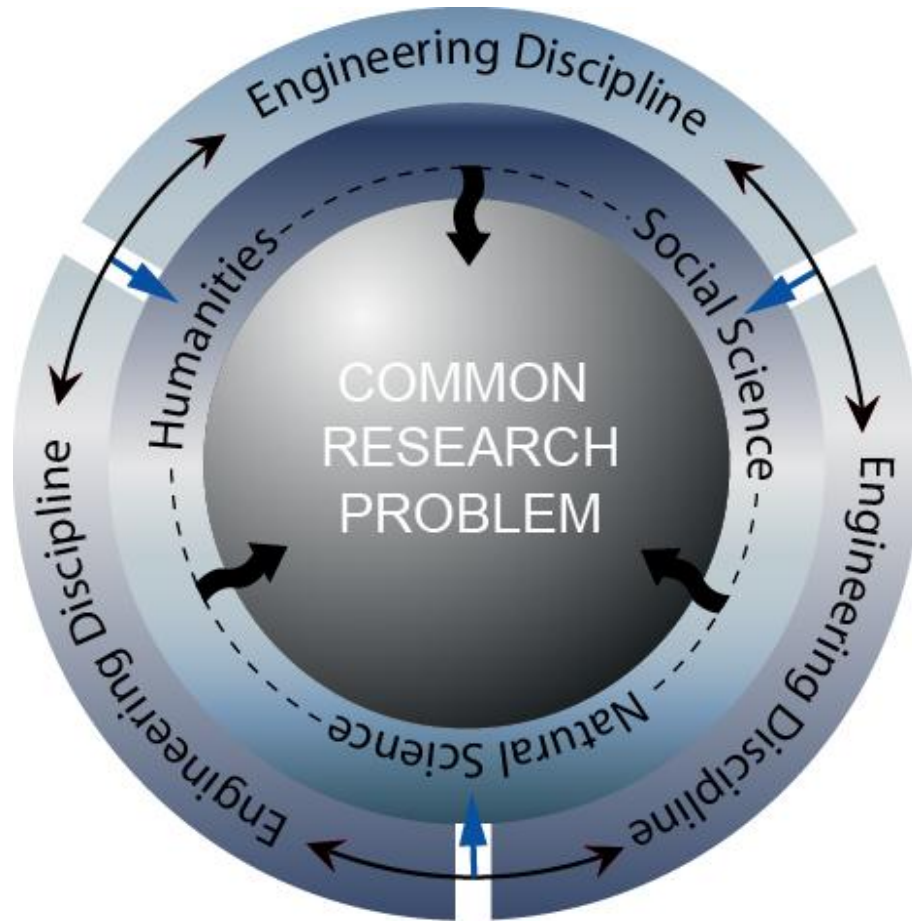


Figure 3.1 Transdisciplinary Research Process

Through the transdisciplinary research process the researchers can plan early and have frequent consultations with the affected communities. This allows them to identify and address the most serious issues before substantial investments are made. Further, researchers from the different families of disciplines should work together with the required utility agencies, government agencies, environmental organizations, and with the developers to insure that such complex problems will be under control.

The three terms of multidisciplinary, interdisciplinary and transdisciplinary are often defined differently by researchers and educators.

The term transdisciplinary is defined by Boothby (2005) as a set of principles, methods, and techniques expressed in a common language that can be located in all disciplines [67].

Klein (2004) defined the terminology of multidisciplinary, interdisciplinary and transdisciplinary approaches as [68]:

“Multidisciplinary approaches juxtapose disciplinary/professional perspectives, adding breadth and available knowledge, information, and methods. They speak as separate voice, in encyclopedic alignment...”

“Interdisciplinary approaches integrate separate disciplinary data, methods, tools, concepts, and theories in order to create a holistic view or common understanding of complex issues, questions, or problem... Theories of interdisciplinary premised on unity of knowledge differ from a complex, dynamic web or system of relations.”

“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...”

“All three terms evolved from the first OECD international conference on the problems of teaching and research in universities held in France in 1970.”

Burger and Kamber (2003) characterized transdisciplinary science as [69]:

Cognitive and social cooperation across disciplinary boundaries

An intention towards the direct application of scientific knowledge in both political decision-making and societal problem-solving

The participation of non-scientific stakeholders within research processes

Peterson and Martin (2005) stated that interdisciplinary research has not produced a combination or synthesis which 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 [70].

Bruce et al., (2004) 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 [71].

“Transdisciplinary refers to knowledge that exists in every individual thus eliminating the need for discipline boundaries.” [72]

D. 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 [73].

3.2.1 Transdisciplinary Research

Taking a step further, we can understand how the practice of ‘transdisciplinary’ research (TDR) transcends the narrow scope of disciplinary views. It challenges the existing boundaries and updates the map. TDR leads to the evolution of disciplines and gives us outcomes that are greater than the sum of the parts [74]. This TDR process not only integrates across disciplines but includes a group of approaches that can generate new, comprehensive knowledge and an overarching synthesis [75]. TDR’s objective is directed at understanding complex issues. Some key examples of the research processes

dealing with complexity include: general systems theory, structuralism, policy sciences, socio biology, feminist theory, and transdisciplinary design and process systems.

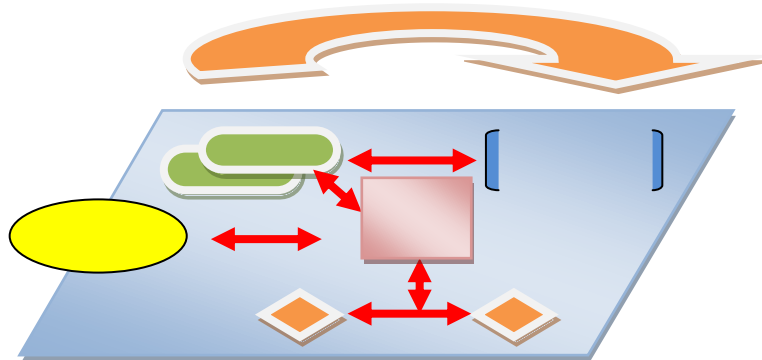


Figure 3.2 Transdisciplinary Research [76]

3.2.2 Transdisciplinary Studies

Transdisciplinary studies are projects that both integrate academic researchers from different unrelated disciplines and non-academic participants, such as industrial managers, technicians, program officials and the general public, to research a common goal and create new knowledge and theory. Transdisciplinarity combines interdisciplinarity with a transdisciplinary participative approach [77].

3.3 Transdisciplinarity Charter

At the First World Congress of Transdisciplinarity (Convento da Arrábida, Portugal, November 2-7, 1994) the following Charter of Transdisciplinarity was adopted [78]:

Article 1: Any attempt to reduce the human being by formally defining what a human being is and subjecting the human being to reductive analyses within a framework of formal structures, no matter what they are, is incompatible with the transdisciplinary vision.

Article 2: The recognition of the existence of different levels of reality governed by different types of logic is inherent in the transdisciplinary attitude. Any attempt to reduce

reality to a single level governed by a single form of logic does not lie within the scope of transdisciplinarity.

Article 3: Transdisciplinarity complements disciplinary approaches. It occasions the emergence of new data and new interactions from out of the encounter between disciplines. It offers us a new vision of nature and reality. Transdisciplinarity does not strive for mastery of several disciplines but aims to open all disciplines to that which they share and to that which lies beyond.

Article 4: The keystone of transdisciplinarity is the semantic and practical unification of the meanings that traverse and lie beyond different disciplines. It presupposes an open-minded rationality by re-examining the concepts of “definition” and “objectivity”. An excess of formalism, rigidity of definitions and a claim to total objectivity, entailing the exclusion of the subject, can only have a life-negating effect.

Article 5: The transdisciplinary vision is resolutely open insofar as it goes beyond the field of the exact sciences and demands their dialogue and their reconciliation with the humanities and the social sciences, as well as with art, literature, poetry and spiritual experience.

Article 6: In comparison with interdisciplinary and multidisciplinary, transdisciplinarity is multi-referential and multidimensional. While taking account of the various approaches to time and history, transdisciplinarity does not exclude a trans-historical horizon.

Article 7: Transdisciplinarity constitutes neither a new religion, nor a new philosophy, nor a new metaphysics, nor a science of sciences.

Article 8: The dignity of the human being is of both planetary and cosmic dimensions. The appearance of human beings on Earth is one of the stages in the history of the Universe. The recognition of the Earth as our home is one of the imperatives of the transdisciplinarity. Every human being is entitled to a nationality, but as an inhabitant of the Earth is also a transnational being. The acknowledgement by international law of this twofold belonging, to a nation and to the Earth, is one of the goals of transdisciplinary research.

Article 9: Transdisciplinarity leads to an open attitude towards myths and religions, and also toward those who respect them in a transdisciplinary spirit.

Article 10: No single culture is privileged over any culture. The transdisciplinary approach is inherently transcultural.

Article 11: Authentic education cannot value abstraction over other forms of knowledge. It must teach contextual, concrete and global approaches. Transdisciplinary education revalues the role of intuition, imagination, sensibility and the body in the transmission of knowledge.

Article 12: The development of a transdisciplinary economy is based on the postulate that the economy must serve the human being and not the reverse.

Article 13: The transdisciplinary ethic rejects any attitude that refuses dialogue and discussion, regardless of whether the origin of this attitude is ideological, scientific, religious, economic, political or philosophical. Shared knowledge should lead to a shared understanding based on an absolute respect for the collective and individual otherness united by our common life on one and the same Earth.

Article 14: Rigor, opening, and tolerance are the fundamental characteristics of the transdisciplinary attitude and vision. Rigor in argument, taking into account all existing data, is the best defense against possible distortions. Opening involves an acceptance of the unknown, the unexpected and the unpredictable. Tolerance implies acknowledging the right to ideas and truths opposed to our own.

Final Article: The present Charter of Transdisciplinarity was adopted by the participants of the first World Congress of Transdisciplinarity, with no claim to any authority other than that of their own work and activity.

The above articles can be summarized as [79]:

- Transdisciplinarity complements disciplinary approaches
- The transdisciplinary vision goes beyond the exact sciences and demands dialogue with the humanities and the social sciences, as well as with art, literature, poetry and spiritual experience
- The recognition of the existence of different levels of reality governed by different types of logic is inherent in the transdisciplinary attitude
- The transdisciplinary attitude involves an acceptance of the unknown, the unexpected and the unforeseeable

3.3.1 Transdisciplinarity Collaborative Process

“One of the broadly agreed characteristics of transdisciplinary research is that it is performed with the explicit intent to solve problems that are complex and multidimensional, particularly problems (such as those related to sustainability) that involve an interface of human and natural systems” [80].

Nicolescu (2005) stated that transdisciplinarity concerns that which is at once between the disciplines, across the different disciplines, and beyond all disciplines [81].

Cronin (2008) defined transdisciplinary studies as: projects that both integrate academic researchers from different unrelated disciplines and non-academic participants to research a common goal and create new knowledge and theory. The key being: transdisciplinarity combines interdisciplinarity with a participatory approach [82].

A revolutionary interpretation of transdisciplinarity was stated by Nowotny [83]: The change in ethos amongst engineers, particularly in the area concerned with finding solutions to complex problems has created a possible feedback loop driving better technical results.

In the recently published Handbook of Transdisciplinary Research, the editorial committee proposed this definition of transdisciplinarity: “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.” [84]

During the past decade, other different approaches of transdisciplinarity were developed and described by several distinguished researchers and educators. From the definitions above, one can easily see that phrases of collaboration, shared knowledge, unity of knowledge, distributed knowledge, common knowledge, and integration of knowledge, integrated disciplines, beyond discipline, complex problems, and societal fields are the

common ones. Although a precise definition of transdisciplinarity is debatable, reviewing the above approaches, definitions, and common phrases, transdisciplinarity may be defined as:

Transdisciplinarity is a collaborative process of a new way of organized knowledge generation and integration by crossing disciplinary boundaries (engineering, natural science, social science and humanities) for designing and implementing solutions to complex problems around the world.

During the last two decades transdisciplinary activities have been expanding all over the world. Many of these activities are published by researchers and educators. Some of them are: [85, 86, 87, 88, 89, 90, 91, 92, 93, 94, and 95].

3.3.2 Transdisciplinarity Educational and Research Activities

The past decade has seen growing interest and investment in transdisciplinary research centers and institutes. This notion of creating national transdisciplinary centers or institutes in which scientists from diverse disciplines would conduct collaborative research and share their knowledge has become increasingly appealing [96].

Recently, the National Institute of Health (NIH) established the Bioengineering Consortium (BECON) to foster new basic understandings, collaborations, and transdisciplinary initiatives among the biological, medical, physical, engineering, and computational sciences. In support of this objective, BECON coordinates and facilitates research grants, training opportunities, and scientific symposia associated with biomedical engineering.

In October 2004, NIH announced new funding for transdisciplinary tobacco use research centers. Seven academic institutions including Brown University, University of Wisconsin, Roswell Park Cancer Institute, University of Minnesota, University of Southern California, University of Pennsylvania, and Yale University have been awarded grants totaling \$12 million by the National Cancer Institute (NCI) and the National

Institute on Drug Abuse (NIDA) to create the Transdisciplinary Tobacco Use Research Centers (TTURC). These centers will study a wide range of research topics such as genetic and psychosocial factors that influence tobacco use and addiction [97].

The Robert Wood Johnson Foundation (RWJF) has committed an additional \$14 million to complement NCI's and NIDA's efforts [98]. The funds will be used for the first year of a five-year project to foster unique collaborations among scientists across many disciplines. Together NCI and NIDA will spend about \$70 million for the effort over five years [99, 100]. These TTURCs exemplify large-scale scientific collaborations undertaken for the explicit purpose of promoting novel conceptual and methodological integration bridging two or more fields [101]. These grants were awarded to: Brown University, the University of Wisconsin, Roswell Park Cancer Institute, the University of Minnesota, the University of Southern California, the University of Pennsylvania, and Yale University. The University of Tokyo is promoting transdisciplinary education at its Hongo and Kashiwa campuses to explore new research fields where various disciplines perform and interact [102].

Many other transdisciplinary research centers and institutes have been initiated during the last decade. The Pacific Rim Transdisciplinary Tobacco & Alcohol Use Research Center engages in research in the U.S. and China. This center focuses on the nations' culturally diverse youth as it examines genetic, environmental, social, and cultural factors influencing tobacco and alcohol use behavior in order to develop more effective prevention programs [103].

The goal of the Transdisciplinary Imaging Genetics Center is to enhance the understanding of brain function in health and disease through facilitation of the development of a new discipline, referred to as Imaging Genetics. The collaborating team of experts from U.C., Irvine and the University of Toronto with experience in genomics, imaging analysis, statistical methods, and complementary areas is viewed as key to accomplish the center goal [104].

Rutgers University has received a five-year, \$6 million grant from the National Institute on Drug Abuse, a component of the National Institute of Health, to establish a center for developing innovative drug abuse prevention programs for young people. The Transdisciplinary Prevention Research Center will be integrated with the Center of Alcohol Studies at Rutgers [105].

The International Center for Transdisciplinary Studies at Jacobs University Bremen was initiated in 2006. The Center's goal is organized research in science and engineering through a program of summer schools, workshops, and conferences as well as individual research with faculty of the Jacobs University. Research interest at the Center includes mathematics, computer science, astroparticle physics, physics of complex systems, chemistry, and various areas of the life sciences [106].

Transdisciplinary Research in Energetics and Cancer (TREC): is a multi-site project funded in 2005 by the National Cancer Institute to encourage transdisciplinary research in energetics and cancer. Funding for TREC began in September 2005 and will continue for five years [107].

The goal of the NIH Resource Core Transdisciplinary Prevention Research Centers (P30) Program is to support environments in which scientists from the basic and applied/clinical disciplines can come together to develop a coherent program of transdisciplinary research. The two specific goals are to encourage:

- 1) Translational research between the basic sciences into development and testing of novel preventative intervention approaches.
- 2) Translation of preventive intervention findings back into basic science laboratory studies that can better explicate underlying intervention mechanisms and effects of basic systems such as neurobiology [108].

“In 2003, NIH funded 8 Centers for Population Health and Health Disparities (CPHHD). The mission of these centers is to understand and reduce health disparities using a transdisciplinary approach with community partners as co-investigators. The present study aims to identify early challenges experienced by CPHHD investigators in working together to achieve the aims of their centers. A 33-item survey was constructed based in

part on a report by the National Academies Committee on Facilitating Interdisciplinary Research. The survey was administered to the 35 CPHHD principal investigators and project leaders in early 2006. 27 surveys were completed by investigators from 42 disciplines; a 77% response rate. Less challenging among obstacles were working with community partners as co-investigators, arriving at a unifying conceptual framework to study health disparities across disciplines, dividing center resources among schools and divisions, and educating trainees in the conduct of transdisciplinary research, with only 25%, 22%, 22%, and 19% of investigators rating these processes as extremely or very challenging, respectively. Almost half of investigators reported they had not yet developed methods for analyzing transdisciplinary health disparities data and over two-thirds (73%) rated this experience as extremely or very challenging. Only one investigator reported being unable to continue her work because of competing commitments from her department. For investigators who had the opportunity to submit their work for peer review, acceptance for publication and scientific meetings was rated as extremely or very challenging only by 8% and 4% of investigators, respectively. Transdisciplinarity has been called a scientific and social imperative. However, early experiences of CPHHD indicate multiple challenges to conducting transdisciplinary research, most notably developing analytic methods and applying research results. Strategies are needed to assist transdisciplinary investigators in developing methods of analysis and applying their work.” [109]

The Burnham Institute for Medical Research is home to a National Cancer Institute (NCI) designated cancer center focusing on basic and translational aspects of cancer research, which offers transdisciplinary training in cancer biology. Training opportunities in cellular signaling, cell death, developmental biology, nanotechnology, bioinformatics, and molecular epidemiology are combined with training in one of the technology centers (i.e. Conrad Prebys Center for Chemical Genomics, Center on Proteolytic Pathways, and the Stem Cell Center) that are developing prototypical tools and technologies for drug discovery [110].

The Transdisciplinary Fluid Integration (TFI) Research Center was established in 2003 by expanding the Shock Wave Research Center in the Institute of Fluid Science, Tohoku University. The main goal of this research center is to address transdisciplinary fluid problems by means of a new research methodology. Fluid science is important to sustainable development of human beings relating to various research fields of importance such as the environment, life science, information technology, and nanotechnology. To solve these problems, TFI is developing the research method by integrating experimental and computational methods. Integration of these methods leads to significant improvements in efficiency and accuracy for solving transdisciplinary fluid problems in science and engineering fields. A new research field of fluid informatics is being cultivated through strong interaction of scientists and engineers in diverse research fields. The research center consists of the core research division for fundamental research and the targeted research division for project-oriented researches [111].

The Center for Transdisciplinary Gender Studies (ZtG) at Humboldt-Universität zu Berlin combines all the aspects considered indispensable for a scientifically-founded analysis of gender relations, bringing together diverse disciplines and people involved in research and forms of critical discussion of the category gender in all theoretical and social areas. ZtG Center is a place for thinking, teaching, reading, writing, filming, speaking, living, discussing, presenting and testing perceptions of gender. In the ZtG researchers, academic staff, students and interested people from Germany and other countries can find a place where they can exchange views and transfer knowledge for the critical reflection of gender [112].

At the Oklahoma Assistive Technology Center, a Transdisciplinary Training Program for Providing Seating Positioning and Mobility Intervention to Children with Developmental Disabilities Who Are 0-3 Years of Age was developed [113].

Jantsch has stated that the structure of the university should be determined by the concept of an integral education/innovation system for which four principal levels are considered: empirical, pragmatic, normative, and purposive levels. The entire education/innovation

system may become coordinated as a multilevel, multigoal hierarchical system through a transdisciplinary approach, implying generalized axiomatics and mutual enhancement of disciplinary epistemology [114].

During his remarks delivered to the faculty in 2000, Dr. Steadman Upham, President of Claremont Graduate University, stated:

“...During the past two years, we have crafted a new vision for Claremont Graduate University. Four strategic objectives have been identified that build on past achievement and now guide all planning and actions (enhancement of academic quality, development of transdisciplinary teaching and research, increased visibility as a national university, and financial reengineering).” [115]

[116] In Chapter 2, Dierenfeld offered us the four models of interaction consultants and described how they recommend lawyers and consultants work with clients in collaborative law and/or collaborative family practice. Here in Chapter 3 we see Figure 3.3, the fourth model. In this transdisciplinary model the respective professionals not only have a seat at the negotiation table, but as a result of mutual sharing of information they are now privy to the full data. They are able to intelligently discuss and input using the data and insights of their colleagues.

Hence, a family professional discussing potential parenting paradigms can do so mindful of any financial challenges that may intervene with an otherwise well-intentioned plan. With all professionals at the table, mutual sharing of data, a deep understanding and appreciation of pertinent issues, the quality of problem-solving can be improved upon from the team models shown in Chapter 2. The transdisciplinary model is best depicted with the Figure 3.3 below [116].

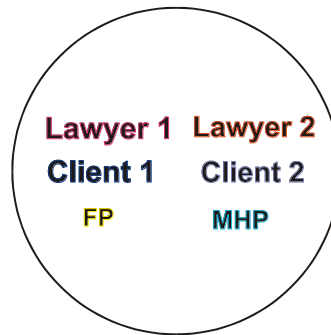


Figure 3.3 Transdisciplinary Model

Network for Transdisciplinary Research (td-net) was created in 2000 by the Swiss Academic Society for Environmental Research and Ecology (SAGUF) and taken over by the Swiss Academy of Sciences (SCNAT) in 2003. Since 2008, the td-net for transdisciplinary research has been a project of the Swiss Academies of Arts and Sciences. It was stated that transdisciplinary research (TR) complements applied research in problem fields characterized by complexity and uncertainty: “There is a need for TR when knowledge about a societally relevant problem field is uncertain, when the concrete nature of problems is disputed, and when there is a great deal at stake for those concerned by problems and involved in dealing with them,” [117, 118].

The Center Leo Apostel (CLEA) was created in 1995 as a transdisciplinary research department. The center’s goal is the development of world views that integrate the results of different scientific and cultural disciplines. Crossing the boundaries of natural sciences, the social sciences, and humanities for knowledge generation is the main objective of CLEA [119].

A series of articles was published by the Russian School of Transdisciplinarity on Transdisciplinary: Sustainable Development, National Security, Forecasting, Biochemistry of Human Body, Strategic Planning and Business Management, Global Natural Cataclysms, Ecological Systems, Preventive Medicine, Ethical and

Technological features, Universal Outlook and more [120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131 and 132].

Around the world universities are working to change their visions of education and research. Ten years ago, the Texas Tech University College of Engineering had the vision to develop the first transdisciplinary graduate education program, thus initiating transdisciplinary education and research into the engineering community and workplace. Raytheon, a large U.S. defense contractor, is a prime supporter of the program. To date well over 100 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.

CHAPTER 4

A SYSTEM-OF-SYSTEMS APPROACH FOR A TRANSDISCIPLINARY DESIGN PROCESS

4.1 Introduction

Terms related to design and design process models are important to the discussion of transdisciplinary research-design process and the framework that is presented in this chapter. What does the term ‘design’ mean? One definition of design is: a process of logical deduction about a set of requirements and constraints. To say, I would like to design an artifact, does not provide any understanding of the proposed design. Specific things must be known about the artifact before the design process can be initiated. For example, we might require the artifact to function in a certain way, certain efficiency, and to be dependable when operating at the specified condition. As indicated in Figure 4.1, design is a process of logical deductions [134]. (Chapter 4 has been adapted from reference 133).

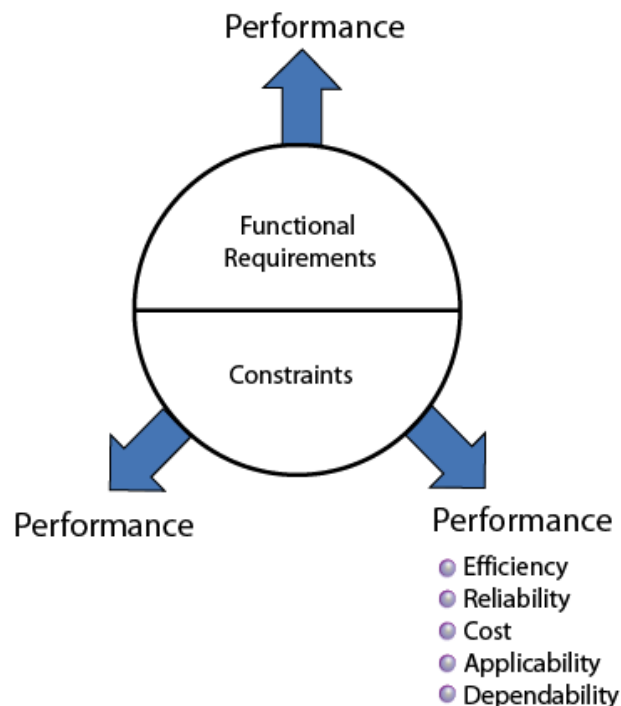


Figure 4.1 Design is a Process of Logical Deduction.

Several definitions of the concept of design put forward by other authors follow:

Engineering design is a purposeful activity directed towards the goal of fulfilling human needs, particularly those which can be met by the technology factors of our culture. And decision making, in the face of uncertainty, with high penalty of error. (Asimov, 1962, [135])

Finding the right physical components of a physical structure (Alexander, 1963, [136])

The performing of a very complicated act of faith (Jones, 1966, [137])

Engineering design is the use of scientific principles, technical information and imagination in the definition of a mechanical structure, machine or system to perform pre-specified functions with the maximum economy and efficiency. (Fielden, 1963, [138])

Design is the process of devising a system, component, or process to meet desired needs. (Ertas and Jones, 1996, [139])

The creation of a synthesized solution in the form of products, processes or systems that satisfy perceived needs through mapping between the functional requirements (FRs) in the functional domain and the design parameters (DPs) of the physical domain, through proper selection of the DPs that satisfy the FRs. (Suh, 1989, [140])

Similar to the quotes presented above, we suggest this new definition of design:

Design is an experience and knowledge-based creative, technical, and managerial activity wherein scientific principles are employed to find a set of solutions for a given task in the physical domain which satisfies functional requirements and physical constraints.

The aforementioned definition of design indicates that more than one satisfactory solution to a given task can be found which meets the functional requirements and physical constraints. The selection of the most suitable design solution can be made by taking the following factors into account:

1. Cost
- 2.
3. Present technology
4. Environment
5. Political and psychological issues

The best engineering solutions are not necessarily the best political solutions. Conversely, the best political solutions may not be the best engineering solutions. For example, the decision to build a 130 story tower in order to have the tallest building in the United States is definitely not the best engineering approach, because high costs and inefficient energy utilization are inevitable. Similarly, when environmental issues are taken into account during a design, the solution may not be the most creative, economically favorable, or esthetically attractive. Lack of experience and knowledge regarding the inputs to a design process will result in uncertainty during the solution decision-making process. In this module, the generic design process is developed from the foundation of common principles applied in the various disciplines. Knowledge input to the design process is assumed to be the information-transformation process required to generate a suitable design solution.

4.2 Important Features of Design

The following model highlights important features of the design process [141].

1. Design is an investigative process (research): In general, the initial step of the design process is to communicate and understand the client's needs and expectations. Related design techniques, previous design solutions, past failures and successes, etc. should then be investigated to seek the solution to the problem at hand. This stage requires knowledge of design methods and broad experience in the area of the technology involved.

2. Design is a creative process (art): A solution to the design problem can be either created or adapted. A solution can be created using personal knowledge, capability, ingenuity, active memory, pattern recognition abilities, random searches of the solution space, lateral thinking, and brain storming, etc. In this stage, the design process is heavily dependent on the gifts and experience of the designer and a feeling for the subject, etc.
3. Design is a rational process (logic-based): Logic provides insight into the design process. In general, developing design solutions involves logical reasoning, mathematical analysis, computer simulation, laboratory experimentation, prototype field testing, etc. Making logical deductions about a set of requirements is a rational process which can be performed with the help of well-known scientific methods.
4. Design is a decision-making process (value-based): The selection of design parameters for a product involves considerable uncertainty. Obtaining an optimum solution to a design problem is the key to the design task. By estimating the value which clients are likely to place on different alternatives, one can arrive at an appropriate decision.
5. Note that not every design problem will demand all four types of knowledge and skills described above.

4.3 Design Methods

Formal or informal procedures, rules, techniques, and tools for designing are called design methods. Intensive effort over the last 20 years has resulted in a significant increase in scientific design methods. A large body of research on new conventional and unconventional design methods has been published in the literature [142], [143].

4.4 Design Process Models

Since the 1960s, numerous design process models have been developed by researchers. In general, the design process begins with an identified need and concludes with satisfactory qualification and acceptance testing of the product. Of course, generating a concept early in the design process is important. This initial concept is then subjected to analysis, synthesis, refinement, and finally development. Design process models can be divided into three categories: those that are based on the essential design activities, those that are based on the phases of evolution of the design object, and those that are based on knowledge.

4.4.1 Activity-Based Design Process Model

A simple example of activity-based models is the three stage model. This model is based on three essential design activities - analysis, synthesis, and evaluation as shown in Figure 4.2. The first activity involves understanding the problem and the generation of an explicit statement of the design process goals. The second activity involves the generation of possible solutions. During the third activity, the validity of possible solutions is tested with respect to the goals (objective or requirements), constraints, and finally the best solution among alternatives is selected. As shown in Figure 4.2, the problem solution can be refined by reexamining the analysis. In other words, the design process is iterative in the sense that the sequence may be repeated until the problem solution converges to a satisfactory conclusion. Asimov pointed out that each cycle is progressively less general and more detailed than the preceding one. Although the three stage design process is the simplest model, there has been widespread agreement on the process shown in Figure 4.2.

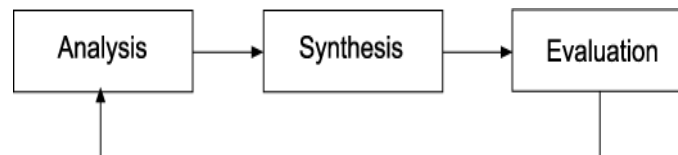


Figure 4.2 Three Stage Design Process

As shown in Figure 4.3, Cross [144] describes design as a four stage process which differs somewhat from the three stage process. This simple four stage model assumes that the final stage of the design process is the communication of the design solution, ready for manufacture or implementation, to the production process. The design activity prior to the communication stage concerns judging the validity of problem solutions against goals and constraints. The problem solution itself arises from the generation of a concept by the designer, usually after some initial exploration of the ill-defined problem space. In Figure 4.3, an iterative feedback loop for design refinement is shown between the evaluation and generation stages.

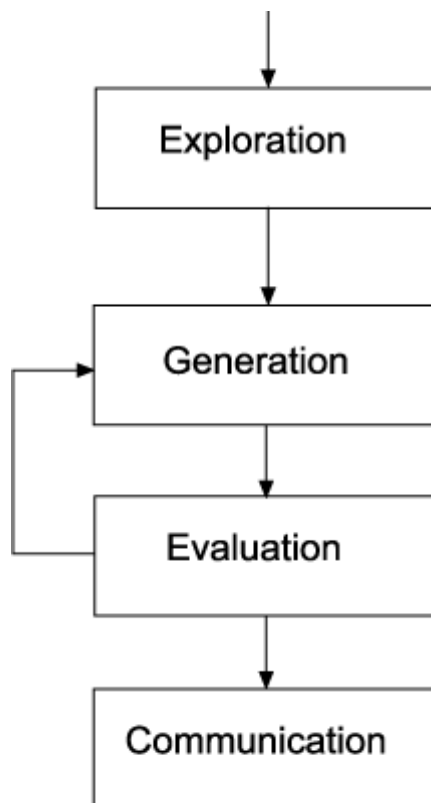


Figure 4.3 Four Stage Design Process

4.4.2 Phase-Based Design Process Model

In the phase-based design model, phases can be expanded with more specific activities or steps as in the activity-based models [145]. Figure 4.4 presents an example of a phase-based model by Wilson [146].

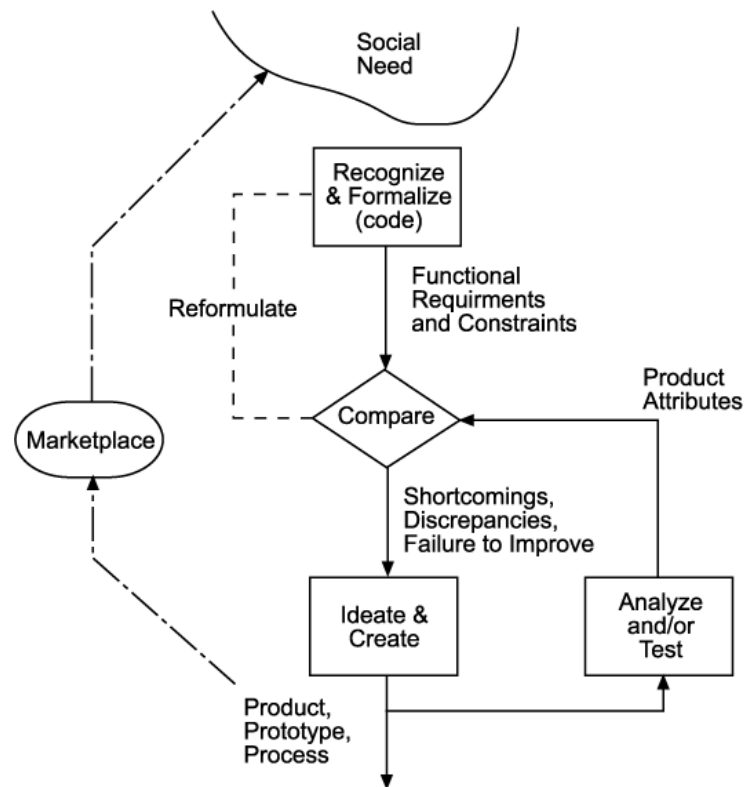


Figure 4.4 Design Process by Wilson

4.4.3 Typical Steps in Engineering Design Project

Ertas and Jones [147] indicated that the typical steps in the engineering design process are as shown in Figure 4.5. They used a combination of step, phase, and important characteristic methods to provide another version of the engineering design process. The process shown in the figure is considered to be generally applicable to most design efforts,

but the reader should recognize that individual projects will often require variations, including the elimination of some steps. This is especially true for design efforts accomplished within small organizations in which the design process is less formal.

The design process begins with an identified need which can be satisfied by the defined design requirements. A design process can be initiated based on an idea for a solution to an existing or identified need or from an idea for a product or process for which it is thought a need can be generated. Many toys are products for which the idea precedes the identified need.

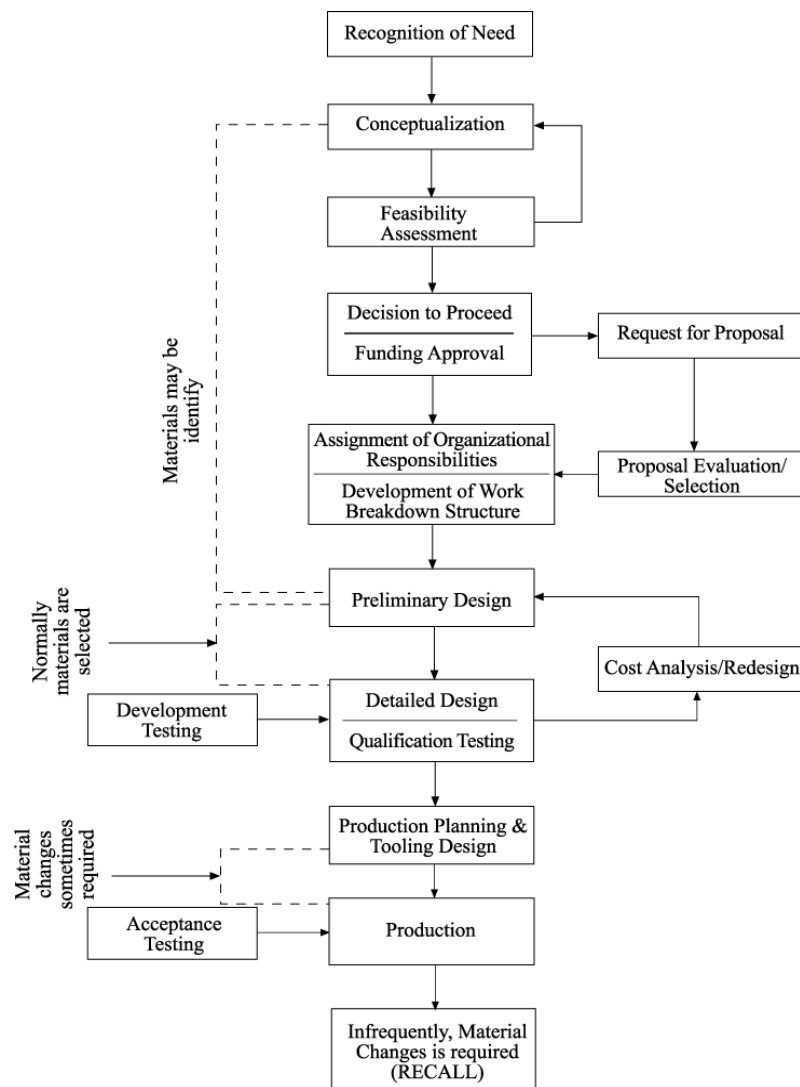


Figure 4.5 Design Process by Ertas and Jones

4.4.4 Recognition of Need

At the beginning of the design process, during the conceptualization phase, it is most important to consider alternative solutions. Once the decision to proceed has been made, it becomes increasingly costly and difficult to make changes. It is also increasingly difficult for the people involved in the process to recognize the value of, or justification for, making significant changes; usually it takes some traumatic event such as deteriorating economical performance to cause a change in the design approach or philosophy. In view of the difficulty of making changes once a course of action has been adopted, what are the important considerations that should be applied to insure that the selected approach is optimum, given the information and data available? The single most important consideration at this stage is thought to be a thorough understanding of the need. A complete understanding of the problem is absolutely necessary to identify the correct solution or solutions.

4.4.5 Conceptualization and Creativity

After the problem has been completely defined, viable solutions need to be identified from which the optimum approach can be selected. Brainstorming, in which a group of participants suggests as many ideas for solutions to the problem as possible in a set period of time, is one technique that has been used to assist in identifying alternate solutions to problems. When several people are involved in the process, this approach may have some merit since the ideas suggested by one person may trigger ideas for better solutions on the part of another. Success in the development of problem solutions, whether as a member of a group or as an individual, relate to the individual creativity. Edward de Bono, in his book on thinking [148], uses the term lateral thinking in lieu of creativity, making the argument that a creative person may narrowly focus on only one solution and not be able to see other alternatives to a problem. The solution may be creative, but there may be other more creative solutions to the problem that need to be considered. Lateral thinking has to do with changing perceptions and concepts so that many viable solutions to a problem are evaluated. According to de Bono, thinking is a skill that can be learned, whereas intelligence is an inherent capability largely determined

by genes. He likens intelligence to the horsepower rating of an automobile engine. The performance of the automobile does not depend on the horsepower rating of the engine but on the skill with which that horsepower is used by the driver. Intelligence is a potential, whereas thinking is an operating skill through which intelligence acts upon experience.

4.4.6 Feasibility Assessment

Assessment of the feasibility of the selected concept(s) is often accomplished as part of the conceptualization task on relatively small projects, but is usually a major element of the overall program on larger projects, sometimes taking several years to complete. The feasibility studies for the Space Shuttle contract covered a period of over two years during which time NASA, aerospace companies, and academic groups considered various vehicle and engine configurations as well as overall system capabilities. The purpose of assessing the feasibility of the concept ensures that the project proceeds into the design phase with a concept that is achievable, both technically and within cost constraints, and that new technology is required only in areas that have been thoroughly examined and agreed upon. The manner in which this is accomplished depends on the size and complexity of the project, but the feasibility assessment period is the time for defining the concept so that design can proceed with confidence that the end product will accomplish the intended purpose within the available resources.

It is of paramount importance to have people with broad experience and good judgment involved in the feasibility assessment phase of the design process. People in charge of the feasibility study effort should be directly responsible for the overall (cradle to the grave) performance and functionality of the product, process or facility-people that have a work- ownership mentality.

4.4.7 Preliminary Design

This phase of the design process bridges the gap between the design concept and the detailed design phase of the effort. The design concept is further defined during preliminary design and, if more than one concept is involved, an evaluation leading to selection of the best overall solution must be conducted. As the design concept is refined during the preliminary design phase, the overall project cost estimate will become more realistic. The overall system configuration is defined during this phase and a schematic, diagram, layout, definition drawing, or other engineering documentation (depending on the project) should be developed to provide early project configuration control. This documentation will assist in ensuring interdisciplinary and intra-disciplinary integration and coordination during the detail design phase. System-level and, to the extent possible, component-level design requirements should be established during this phase of the effort. Establishing requirements is a function involving computation and analysis, literature search, vendor equipment evaluation, previous experience, discussion with experts in the particular field, good judgment, and testing (when absolutely necessary). It is costly to run test programs, and thus it is desirable to minimize testing during the preliminary design phase of the project.

The requirements established during the preliminary design phase of the project form the basis for the component specifications developed during the detail design phase. If the requirements are too stringent, the project cost will escalate and (possibly) no supplier will be found willing to bid on the item in question. If the requirements are too lax, the overall system requirements may not be met, which could lead to dire consequences for the overall project. An additional problem with loose requirements is that they must be tightened-up later, sometimes after the initial contract for the component has been consummated, with increased cost. The importance of establishing valid design requirements at the outset is thus apparent. Preparation of system test, checkout and maintenance procedures at an early stage in the design often helps in that regard. The process of thinking these procedures through may help in quantifying the various parameters and thus provide a valid basis for component design.

4.4.8 Detailed Design

The intent of the detailed design phase is to develop a system of drawings and specifications that completely describes a proven and tested design so that it can be manufactured. At this design phase, all the various disciplinary organizations are actively involved in the synthesis/analysis process, resolving the system design concept into its component parts, evaluating components to validate previously established requirements and specifying those design requirements left undefined, and assessing the affect of the component requirements on the overall system requirements. As component requirements are finalized, specifications can be prepared for those components that will be manufactured.

For system components that are manufactured internally, detail drawings are prepared that specify the necessary dimensions, the materials of construction, the surface treatments, machining techniques, test requirements and any other information necessary for fabrication.

4. 5 Knowledge-Based Design Process

[149] Knowledge-Based Design (KBD) is a new product development process evolved from Artificial Intelligence (AI). KBD represents a great opportunity to improve the speed and effectiveness of the product development process, to reduce the time to create a new design, to refine an existing design, and to provide a significant savings.

The approaching 21st century is bringing pressure toward more integration, interdisciplinary cooperation, and international collaboration. We have great pressure to convert the integrated–artifact–design process “from a thing of chance and adventure to a regular understood business.” The various entities of our society are redefining themselves to be able to play an effective role in this new order. As engineers, system designers, system integrators, engineering managers, and engineering executives, we are constantly on the outlook for ways and methods of materializing the integration objectives in the hope of delivering a more robust, high–quality line of products. [150]

Although the integrated–artifact design process using integrated tools has not reached maturity, achievements during the previous decade should not be underestimated. The Boeing 777 was designed one hundred percent digitally, utilizing 3–D solid modeling technology. Boeing invested more than \$1 billion in CAD infrastructure for the design of the 777. Such highly sophisticated packages as the CAD/CAM/CE system, CATIA (Computer-Aided Three–Dimensional Interactive Application), EPIC (Electronic Pre–Assembly Integration), and ELFINI (Finite Element Analysis System) were used during the design, modeling, and development of the 777. Through interdisciplinary team management, 238 teams, (3,500 people) were integrated to provide knowledge-sharing concurrently rather than sequentially. All countries and corporations involved were linked by a computer network which consisted of mainframe and workstation installations in the Puget Sound area, Japan, Wichita Kansas, Philadelphia Pennsylvania, and other locations. Over 3 million parts were developed and organized in an integrated database that allowed designers to provide a complete 3–D virtual mock–up of the aircraft. When the 777 is compared with earlier aircraft (757 and 767) designs, it is clear that Boeing achieved the following improvements [151]:

- Elimination of more than 3,000 assembly interfaces, without any physical prototyping
- 90% reduction in engineering change requests (6000 to 600)
- 50% reduction in cycle time for engineering change requests
- 90% reduction in material reworks
- 50 times improvement in fuselage assembly tolerances
- Reduction of development time from 12 years to 5 years
- Enhanced reliability and productivity at lower cost
- 804 built as 08-31-2009

The Boeing 777 is the first commercial, large-scale complex system design using the concept of a Knowledge Based Engineering (KBE) platform. Knowledge pertaining to design can be organized in a computer database in terms of design objects. Such information may consist of statements about the physical aspects of the artifacts such as

function, data, and control. This information is called *technical knowledge* pertaining to design objects which have been created and produced to accomplish specific goals. Although a vast amount of technical knowledge exists about design objects today, it is not currently in an organized form in a computer database. Obviously, a key part of any organized integration is to agree on the standards for such databases.

In the past, obtaining agreement on standards between corporations has been very difficult. But, due to the widespread use of computers and cost-cutting pressures from internationalization, the environment is now more conducive toward complete standardization. For example, OASIS is a nonprofit, international consortium dedicated to accelerating the adoption of product-independent formats based on public standards. OASIS standards include XML, SGML and HTML as well as others that are related to structured information processing. Members of OASIS are providers, users, and specialists of the technologies that make these standards work in practice.

XML is one such tool that can be used to improve communication between computer-based systems. The XML language consists of rules to create a markup language that leverages existing infrastructure. The rules ensure that a single compact program, an XML parser, can process all these new languages. Due to its extensible and meta-level properties, XML potentially enables the exchange of information not only between different computer systems but also across national and cultural boundaries.

Engineers can employ optimal tools for managing the creation and revision of particular content. For example, text documents can be created in a word processor; accounting information is organized in spreadsheets, while engineering drawings are built in CAD/CAM/CE software. Once the content is created in differing forms using various tools, it is then imported into an advanced integration tool to enforce content integration using XML standards and dictionaries.

During the solid modeling of the Boeing 777, it became apparent how limited the integration was for existing CAD tools. Some of the subcomponents design for the 777

systems could not be integrated with the 3–D solid modeling tools. The obvious reason was the difficulties of translation among CAD systems.

4.5.1 Design Repositories

Traditionally, design information, schematics, drawings, specifications, requirements, etc., were stored in paper repositories. The use of CAD/CAE processes has moved some of this information storage to electronic format; however, designers and engineers must have access to many types of information other than CAD/CAE files to support the design of complex systems. Engineering knowledge, including previous designs of related components and systems, must be effectively reused in new designs to provide the most cost-effective and best overall solutions. How and why are as important as what to the design team. Thus, electronic repositories in which all types of design-related information and knowledge from across the disciplines can be stored and then rapidly and easily retrieved by designers are necessary. Such design repositories greatly enhance knowledge-based design by facilitating the representation, capture, sharing, and reuse of corporate design knowledge. Companies typically refer to their store of corporate knowledge as design databases; however, these databases are beginning to transition into forms more like the design repositories indicated above. This need for industry to reform their knowledge databases is being addressed by emerging research related to design repositories.

Design databases are static, homogeneous, and data oriented while design repositories must be dynamic, heterogeneous, and knowledge-oriented. Databases are used to store limited representations of artifacts; such as, drawings, CAD models, CAE models and results. Design repositories provide design-specific information: requirements, specifications, limitations, general knowledge and data from across the disciplines. They also provide design rules, simulation models, information related to previously designed components and systems. Not only will images, CAD models, and unstructured text be provided in design repositories, but they will also include mathematical simulation models, structured text, animations, video, and other types of information. Design

repositories will also provide such capabilities as a search for information on existing components and systems that satisfy required functions, performance and behavior simulations, automated reasoning and comparison of design options, and more explicit decompositions of physical and functional aspects of a design with cross-mappings. Enough information, knowledge, design and analysis procedures, and active models will be included in design repositories to allow a designer to select components for a subsystem and run simulations to determine performance or otherwise test the proposed subsystem. Clearly, there will be a need for many design repositories to house all of the information required, and there will be a need for standard formats and protocols to represent the form, function and behavior of components, systems, and other artifacts. Just as clearly, it will take some time for these design repositories to be generated and mature to a point where they can support the design of complex systems.

4.5.2 Collaborative Design Framework

Because engineering systems continue to increase in complexity, the membership of design teams must increase in number and in diversity to include not only designers but process planners, manufacturers, clients, etc., as well. The ability to collaborate and communicate seamlessly among the members of a design team is particularly critical to the success of complex system design. The environments in which design teams function are sure to become more geographically and functionally distributed while providing the capability to support more direct and more effective interaction and coordination. Numerous knowledge and data repositories, likely distributed and frequently discipline-oriented will provide specifications, design rules, constraints, and rationale to designers. Evolving designs along with design artifacts and rationale will be stored in databases accessible to all members of the team. These databases will provide the capability to generate various snapshots of the evolving design objects at various levels of abstraction. The design environment must also include a workflow management capability to coordinate and manage the overall design process.

The high speed, distributed computing capabilities required to support such new engineering design processes are being developed and are available. The high bandwidth network which connects the team members must provide effective exchange protocols to maximize the potential of the collaborative information sharing process because members of the design team will likely utilize systems, applications, models, data structures, etc., with form and content typical of their specific disciplines. Design applications utilized by the design team must communicate with other applications used by manufacturing, production, process planning, management, etc. through various networks.

4.5.3. Rethinking the Design Process

The design process is an information processing activity for selection of a means to satisfy identified needs and to solve defined problems. It is a process of gathering information (knowledge) about the problem structure and using this knowledge in discovering potential problem solutions. As shown in Figure 4.6, design knowledge, which defines the information space, is input to the design process. Information used in design may apply to different abstractions of the design process and to different abstractions of design descriptions [152]. For example, knowledge about how components interact in design as well as knowledge for different subcomponents of complex designs may be included in the information space. Knowledge about political, environmental, and physiological issues may also be included to aid in making design decisions. Knowledge in axiomatic character, mathematical formulations, rules and laws may also exist. Information input from the information space is typically manipulated through an information-transformation process to filter solutions that meet the objective of the design.

The basic scheme of design evolution depends on two processes [153].

Generation process

Testing process

As shown below in Figure 4.6, [154] through the information–transformation process, the generator produces a variety of new forms of knowledge which did not previously exist. The test (verification) process extracts generated ideas and knowledge and filters them so that only those that are well-fitted to the environment pass. Objectives of the design can be met, providing that adequate relevant knowledge, enough process direction (defining goals, managing, leading, and controlling towards achieving these goals) is available, and the influences of the environment do not exceed certain constraints and limiting resources.

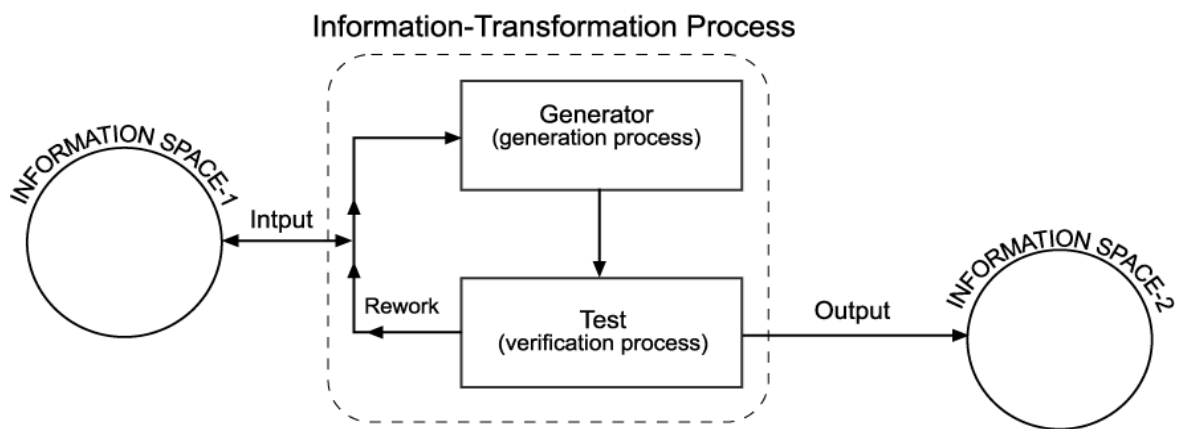


Figure 4.6 Information Transformation Process

Consider a problem structure which may lead to a solution that meets the design objective. The search for problem solution begins along the possible paths of a tree. Knowledge–transfer processes can be used for each path as processes for seeking a solution for the design problem. In other words, there are several processes (as many as the number of paths and branches) for gathering knowledge about the problem structure that will be valuable in discovering a solution to a design problem. As shown in Figure 4.7 the value

is indicated at the end of each path. Of course, a partial path solution is not a solution to the design problem, regardless of the value of the partial path, the total path results in a zero value if it does not lead toward a problem solution. A similar approach can be used for a decomposed complex system.

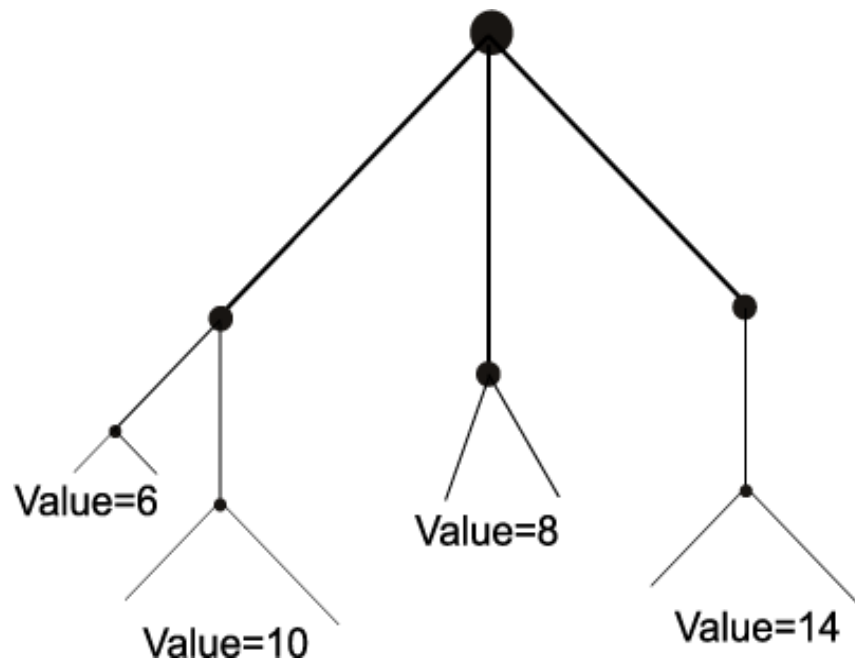


Figure 4.7 Path Tree for Design Solution

4.5.4 Proposed Knowledge-Based Design Process

As shown in Figure 4.8 proposed knowledge-based design processes can be divided into three domains:

1. The first defines the information space which includes all the available information necessary to develop the requirements
2. the second defines the problem space, this stores requirements derived from the information space
3. the third defines the solution space that includes design objects developed through the design object development process

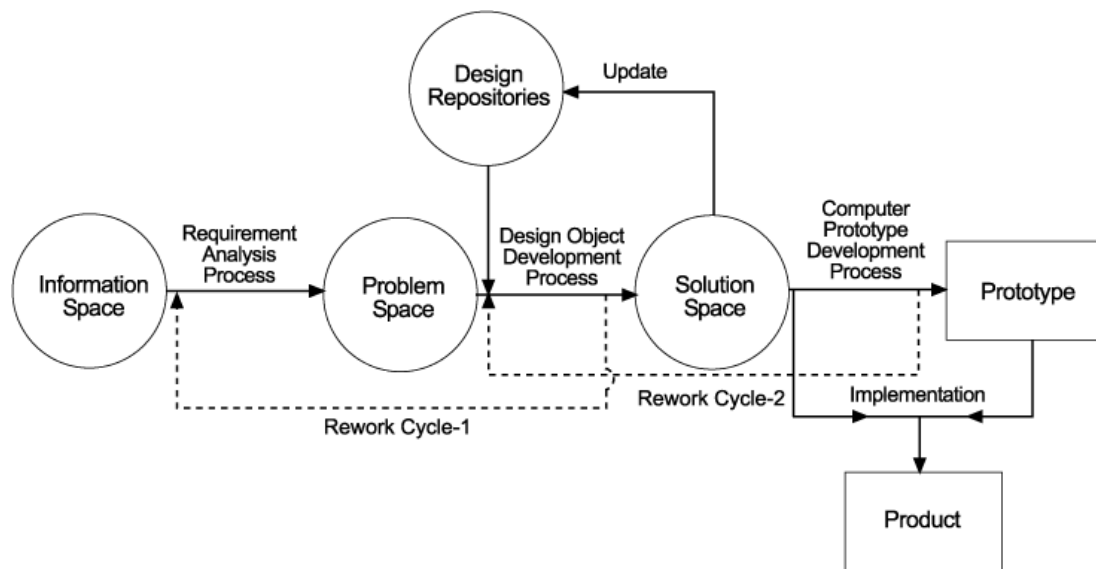


Figure 4.8 Proposed Knowledge-Based Design Lifecycle

Design objects needed to satisfy a given set of requirements can be retrieved from design repositories. It is also important to note that any new or modified design objects developed will be used to update the design repositories. As noted from this figure, rework cycle-1 is used to capture additional information to refine the design requirements.

After the solution space is completely developed, a computer model is created to test the design before the physical implementation phase starts. During the computer model development process, if there is a need for rework, rework cycle-2 is used. Prototype and solution space are the input to the implementation phase to produce a new product. The design requirements both drive and control the product design throughout the process.

Design requirements are especially important during the early phases of the design effort, because they serve as the principal guidelines for the product design team.

Requirements can be considered in three groups:

- Functional requirement
- Non-functional requirement
- Constraints

Below are listed the three main sources of information concerning the design requirements:

- **Customer:** One of the primary jobs facing the design team is to determine *what is to be done* for the customer. *What* does the customer really need? If the design team fully describes the product in terms of requirements and constraints, then they have accomplished one of the most important steps in the design process.
- **Company for which the design is being developed:** The Company (customer) may impose restrictions on the design team because of company limitations. For example, a company may not have a component available in the size needed for the proposed design, and the design team is expected to use one of the available component sizes, if possible.
- **Organizations having authority to impose restrictions by standards and laws to protect the public from injury or loss of property:** There are numerous organizations, governmental and private, that exist to set standards. These organizations generate and promulgate a large number of standards which affect the design, manufacture, and utilization of essentially all products. In addition, international standards are becoming more important such as ISO 9000. [155]The latest edition of the world's most widely used quality management standard that documents quality certification and audit requirements is ISO 9001: 2008. It consists of a series of 24 standards that have been adopted by the European Community (EC) as international standards specifying how quality control is to be established and maintained. By the end of 2007 at least 951,486 certificates of

conformity to the previous edition, ISO 9001: 2000, had been issued internationally.

Additionally, new technology, the user community, competitors, and subcontractors are potential requirement sources. The requirements are so critical to the ultimate design functionality and cost, they must be factored in early in the design development process. It is absolutely essential that all project team participants have a complete and agreed-to understanding of the design requirements. A good example of what can happen as a result of misunderstanding the design requirements occurred during a large scale and costly missile defense program in the late 1950s. During the requirements development process there was confusion between disciplinary organizations as to the meaning of one of the major system design requirements. Unfortunately, this confusion did not become apparent until late in the design process, when the overall systems checkout and test procedures were being prepared. The confusion was related to the meaning of the terms automatic, semiautomatic, and manual used during the requirement development. At significant cost, the mechanical design group had provided the functionality and the capability for all three modes of system operation based on their understanding of the terms. Unfortunately the control system design group had a different interpretation of the terms, and thus, did not provide the desired functionality and capability. Consequently one of the major design requirements could not be satisfied [156].

It is essential to have well-defined and well-controlled requirements, but it is also important to minimize requirement changes as the systems are implemented. Changes to the design requirements during the design process can have a profound and detrimental impact on the final quality of the design. In many high-tech companies, aforementioned problems may cause long lead times for the design effort. On large-scale complex systems, it is common to experience requirements problems late in the design process.

4.5.5 Quality Function Deployment (QFD)

[157] Quality Function Deployment (QFD) was developed in Japan from the early 1950s and into the 1970s and has been successfully used in the United States since the late

1970s. It was originally introduced into Japan in 1948 by W. Edward Deming who was requested and hired by the Allied Command Force to aid in the rebuilding of the manufacturing capability in Japan. Deming was at the time a statistical professor with New York University and a statistics consultant in private practice. Deming was the person who introduced Japan to the quality movement and completely turned business and industry around as they rebuilt after WWII. The principle quality award given each year in Japan is named the Deming Award as a way of demonstrating their appreciation for his assistance.

QFD is a method for identifying customer requirements and assuring that *the voice of the customer* is integrated into a design process for product development. The five stages of the QFD chart are shown in Figure 4.9. The procedure for documenting information in this chart is as follows [158]:

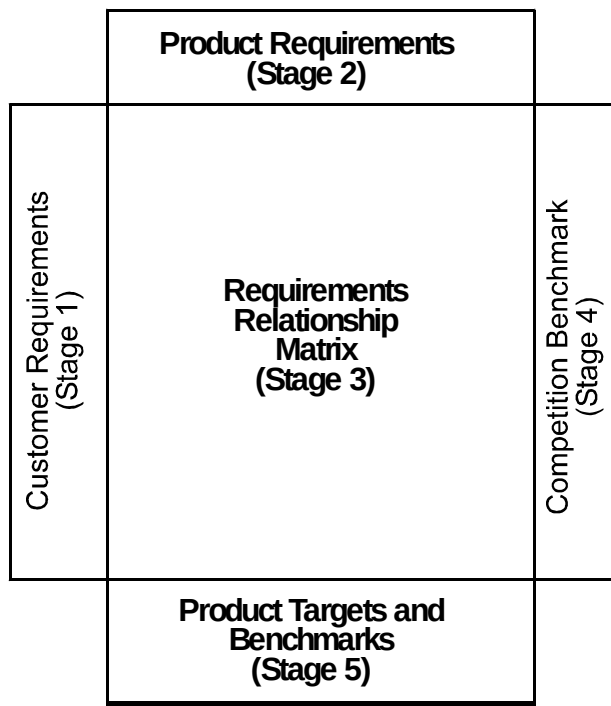


Figure 4.9 QFD Design Requirements Matrix

- *Stage 1*- includes customer requirements and needs (was discussed previously).
- *Stage 2*- includes the list of product requirements. The customer's subjective and non-technical requirements are translated into (corporate language) measurable product requirements (or "hows") in Stage 2. These requirements are developed by design engineers to satisfy the customer requirements. The customer requirements tell us what to do and the product requirements tell us how to do what needs to be done.
- *Stage 3*- involves developing a matrix of product design requirements from customer requirements and product requirements. This relationship matrix is used to verify and improve the fidelity of the translation of customer requirements into measurable product requirements. By ranking the relationship between two requirements and characterizing the strength of this relationship as strong, medium, or weak, product requirements are identified in quantifiable terms. Once all project team participants have an agreed-to understanding of Stages 1, 2, and 3, an important initial attempt has been made to improve product planning.
- *Stage 4*- the proposed design is compared with competitors' products through what is referred to as competition benchmarking. Benchmark design attributes are compared with the list of customer requirements by using a scale of 1 to 5, with 1 being not satisfied and 5 being completely satisfied.
- *Stage 5*- the technical difficulty of each product requirement which needs to be achieved is ranked. Also the target values of each product requirement are set. The technical difficulty of achieving each customer requirement listed in Stage 1 in terms of the changes defined by the product requirement is scaled between 1 and 5, with 1 being not achieved and 5 being completely achieved.

Figure 4.10 below shows a simplified model of Quality Function Deployment for a cellular phone. The potential customer needs (requirements) are listed as the rows of the matrix and the product requirements are listed as the columns of the matrix. The correlation between customer requirements and product requirements are marked with strong, medium, and weak relationships. If the correlation cells are blank, that indicates

there is no correlation between two requirements. To understand the market position of the product, benchmarks for each competitor's values are also shown. Finally, the target value of each product requirement is defined and target difficulties are shown.

		Product Requirements								Benchmarks			
		material toughness	material yield strength	aesthetic	robust design	cost	improved shape	size	time to dial				LCD screen
		Competitor 1	Competitor 2	Competitor 3									
Customer Requirements	looks good			⦿		○	▲			○	5	1	3
	crack resistance	⦿	○								1	3	5
	water resistance				⦿	○					1	3	5
	big screen							⦿		▲	3	3	3
	easy to operate							○	○		1	3	5
	easy to handle						○	▲			3	4	4
	easy to carry							⦿			3	5	5
	Inexpensive					⦿					5	3	3
	Units	^{0.5} psi(in)	psi			\$		in	sec				
	Target Value	20	30			125		2x4	8				
	Technical Difficulty	5	3	5	4	4	3	3	3	2			
		Product Targets & Benchmarks											

● Strong Relationship = 5

○ Medium Relationship = 3

▲ Weak Relationship = 1

Figure 4.10 QFD Design Requirements Matrix

4.5.6 Requirement Decomposition

Due the fact that not all requirements are equally important, they can be arranged hierarchically. Higher level requirements may be vague and should be decomposed into a number of sub-requirements. An example of requirement decomposition is shown below in Figure 4.11. Decomposition of the requirements should be carried out to a *simple* level so that the requirement is self-evident at the lowest level. In other words, requirements have operational status [159]. As a general rule, decomposition should be done from the highest (most abstract, least concrete) level to the lowest (least abstract, most concrete) level.

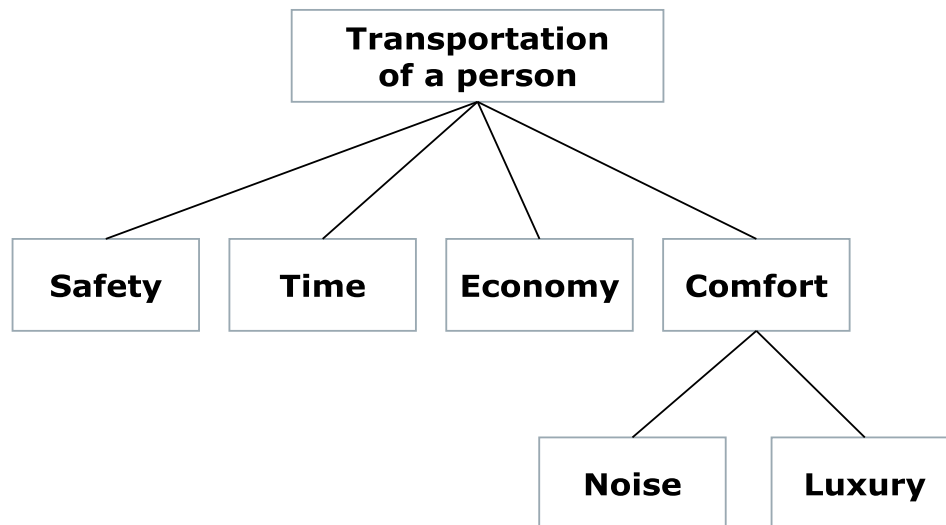


Figure 4.11 QFD Requirements Decomposition for Transportation of a Person

4.5.7 Requirement Traceability (RT)

[160] Requirements traceability is generally practiced in software development lifecycles and in the manufacture of high-reliability products and systems such as medical equipment and aerospace components. This important practice, however, is not widely known and implemented in other design disciplines. It should be a vital part of any system development lifecycle to make sure that (1) the customer needs, (2) the functional

requirements, and (3) the constraints of the design are considered in sequence during the development phases to make the final product/service fully compliant with the original requirements. RT provides stakeholders with the means to show compliance with requirements. Maintaining system design rationale, establishing change control and controlling maintenance mechanisms are a few of the many benefits of this approach [161]. In other words, RT is used to ensure continued alignment between stakeholder requirements and various outputs of the system development process [162]. RT is a very important part of requirements management and engineering practice, in that it provides a very useful tool to establish product quality with maximum customer satisfaction.

Requirements are features, functions, capabilities, or properties that a system must possess. Requirements state the customer or end-user needs and solution constraints. The traditional way of distinguishing requirements from design is that the requirements represent **what** the system is supposed to have or do (i.e., the whats) whereas the design is **how** the system will accomplish the whats (i.e., the hows).

The system requirements should be documented in a requirements specification document and the requirements should be communicated and agreed upon by all stakeholders. The design activities and decisions as well as test activities are based on this requirements specification document since it states what the system is supposed to do. Requirements management can be defined as the process of eliciting, documenting, organizing, and tracking changing requirements and communicating this information across the stakeholders [163].

RT, according to a widely accepted definition, is “ability to follow the life of a requirement, in both forward and backward direction, i.e., from its origins, through its development and specification, to its subsequent deployment and use, and through periods of ongoing refinement and iteration in any of these phases” [164].

RT can be divided into two parts [165]:

- **Pre-requirements traceability (pre-RT)** refers to the ability to describe and follow those aspects of a requirement's life prior to its inclusion in the requirement specification document (System/Subsystem Specifications, Software Requirement Specifications)
- **Post-requirements traceability (post-RT)** refers to the ability to describe and follow those aspects of a requirement's life that result from its inclusion in the requirement specification document (requirements deployment and use)

During requirement allocation, all system components (hardware, software, human-ware, manuals, policies, and procedures) created at various stages of the development lifecycle is linked to requirements. Therefore, tracing requirements allows developers to easily ascertain the impact of any changes.

There are many different views of traceability depending on the stakeholder's view of the system. To the customer, traceability could mean being able to ascertain that the system requirements are satisfied. The developer's concern with traceability may be how a change in a requirement will affect the system, i.e., "What modules are directly affected?" and "What other modules will experience residual effects?" To a test engineer, traceability means making sure that each requirement is being tested. Full requirements test coverage is very difficult to achieve without RT [166].

Many organizations consider RT as a mandate, a contractual requirement to be satisfied. Some organizations, on the other hand, view traceability as an important process in the development of a quality system. Some consider it a must for survival [167].

4.6 Transdisciplinary Research Process (TD-RP): System of Systems Approach

So far different kinds of design processes for product development have been discussed. In this section, a new framework for transdisciplinary research process is proposed to

design and implement new and practical solutions to difficult global problems of our time. The System of Systems (SoS) approach has many parallels with the transdisciplinary research process. Hence, throughout this section many concepts from SoS will be adapted to create new frameworks for TD activities. This section will demonstrate an approach to the understanding and justification of the paradigm of transdisciplinarity as the unifying paradigm of engineering, humanities, natural science, and social science.

The world 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 don't 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 world as we know it. For example, the Financial Post reports a new crisis is emerging, a global food catastrophe that will reach further and be more crippling than anything the world has ever seen [168]. One of the largest public health issues of our time is the world water crisis. Nearly 2.5 billion people (roughly two-fifths of the world's population) lack access to safe drinking water and sanitation [169].

A rising tsunami of energy problems is beginning to threaten 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.

4.6.1 Time for a Survey

This is a good place to check with the transdisciplinary community to see if they believe that a good framework would help them solve the complex problems. These problems often occur in the working of the issues that come up during the discussions and often require many different disciplines and outside groups working together for the best

solutions. Chapter five gives us the development of the survey. Chapter six then explains the analysis of the results of the survey which confirms to us to continue with the framework suggested in this chapter for solving the complex problems and issues in transdisciplinary research and education.

4.6.2 Family of Disciplines

Family of disciplines (FOD) can be defined as the grouping of disciplines with similar characteristics. Simply, FOD can be grouped as [170]:

Engineering: Engineering is a discipline of applying technical, scientific and mathematical knowledge to implement and design an art effect. FOD of engineering can be grouped as:

- Mechanical Engineering
- Electrical Engineering
- Civil Engineering
- Chemical Engineering
- Computer Engineering
- Petroleum Engineering
- Industrial Engineering and etc.

Natural Science: The term natural science refers to a naturalistic approach to the study of the universe. FOD of natural science can be grouped as:

- Astronomy
- Biology
- Chemistry
- Earth science
- Physics

Cross-disciplines: Natural science disciplines may share a number of cross-discipline fields. For example, physics plays a significant role in the other natural sciences as represented by astrophysics, geophysics, physical chemistry and biophysics. Likewise, chemistry is represented by such fields as biochemistry, geochemistry and astrochemistry. Environmental science also draws multiple natural sciences.

Social Science: The FOD of social sciences are concerned with the study of the social life of human groups. FOD of social science can be grouped as:

- Anthropology
- Communication studies
- Economics
- Human geography
- History
- Political science
- Psychology
- Sociology
- Education

Education, as a social science sub-branch, is defined as:

“In its broad sense, education refers to any act or experience that has a formative effect on the mind, character, or physical ability of an individual...In its technical sense education is the process by which society, through schools, colleges, universities, and other institutions, deliberately transmits its cultural heritage - its accumulated knowledge, values, and skills - from one generation to another” [171].

Humanities: The humanities are FOD which study the human condition, using methods such as analytic, critical, or speculative, mainly using empirical

approaches of the natural and social sciences. FOD of humanities can be grouped as:

- Classics
- History
- Languages
- Law
- Literature
- Performing Art (music, theatre, dance)
- Philosophy
- Religion
- Visual Art
- History of humanities etc.

Mathematics, statistics and computer science provide many tools and frameworks used within the natural sciences. Mathematics is traditionally considered among the family of liberal art and statistics among the humanities.

As shown below in Figure 4.12, transdiscipline can be defined as system of disciplines or discipline of disciplines or integrated disciplines which is a result of proper integration of family of disciplines. Collaborative effort among family of disciplines to solve a common problem may require use of shared concepts and methods: integration of science and engineering principles.

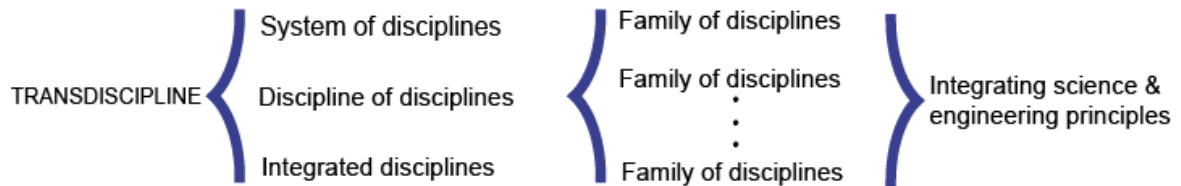


Figure 4.12 Creating Transdiscipline

The disciplines of engineering, natural science, social science, humanities have lived and worked together for ages. They are branches of one family tree - family of disciplines (FoD).

As can be seen from Figure 4.13, information (consists of data organized to characterize a particular situation, condition, or context) is fed through the root of the tree. This information is seemingly integrated to develop new meaning (knowledge) by all the disciplines specific to their culture (consists of concepts, methodologies, tools and methods).

As shown in Figure 4.13 below, a new concept, Transdisciplinary Knowledge, can be generated by crossing diverse knowledge cultures (engineering, natural science, social science and humanities). This process may provide a shared common collection of knowledge to enable us the discovery of new approaches in education and research that lead to alternative solutions for the difficult problems that face civilization. It is true to say transdiscipline is not a new discipline. What is clear is that the world problems are getting more complex to solve, and there is a need for new tools and methods to deal with difficult problems. The disciplinary approach is not adequate to deal with them.

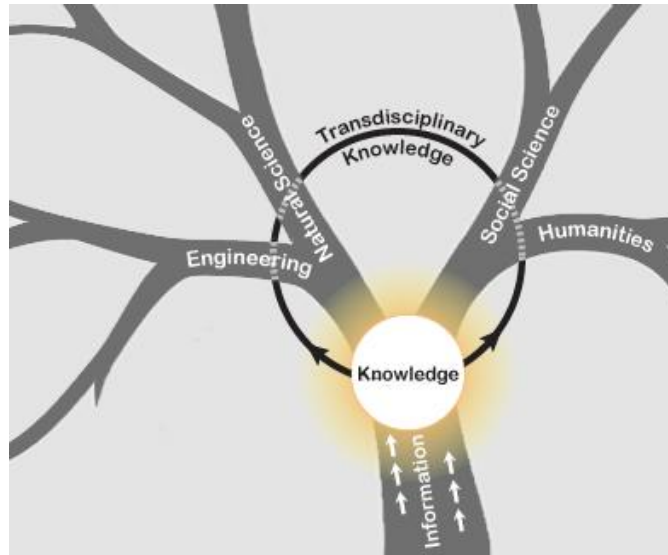


Figure 4.13 Crossing Disciplinary Boundaries

The transdisciplinary research process can be developed in direct analogy with system of systems (SoS) approach. The description of a SoS is:

“System of systems is a collection of task-oriented or dedicated systems that pool their resources and capabilities together to obtain a new, more complex, 'meta-system' which offers more functionality and performance than simply the sum of the constituent systems” [172].

A similar analogy can be used for transdiscipline (Discipline of Disciplines (DoD)). This process pools resources and capabilities of diverse disciplines together to obtain a new shared common collection of knowledge to enable us the discovery of new approaches that lead to alternative solutions for the growing complexity of today’s grand challenges. As defined in the SoS approach, performance of DoD depends on how diverse disciplines work together **not** how each of the disciplines perform when considered separately. We can also state that selectively and collectively organizing of DoD (integrated disciplines) connect to provide a research capability that is greater than the sum of the contributing disciplines.

In the SoS approach, to deal with complex problems other fields will need to be drawn upon for methods, insights, and models. Similarly, in the transdisciplinary approach, to deal with complex problems, common shared concepts, methods and tools from diverse disciplines are used. Observing that the SoS approach has many parallels with transdiscipline (DoD), we can now adapt the framework developed for many years for SoS to DoD.

4.6.3 Transdisciplinary Interoperability

System of systems operability is defined as:

Interoperability is the ability of a system or a product to work with other systems or products without special effort on the part of the customer. Interoperability becomes a quality of increasing importance for information technology products as the concept that "The network is the computer" becomes a reality. For this reason, the term is widely used in product marketing descriptions.

Above definition can be adapted to transdiscipline as:

Interoperability is a property referring to and the ability of researchers from diverse disciplines to work together (inter-operate) to solve global complex problems, taking into account social, political, and organizational factors that impact transdisciplinary research process performance.

Three levels of system of systems interoperability execution are given by Figure 4.14.

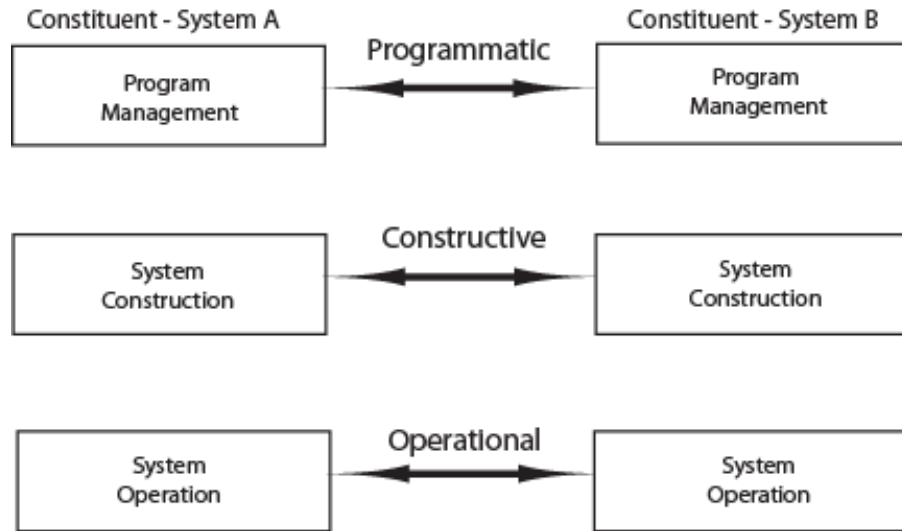


Figure 4.14 System of Systems Interoperability Execution

Figure 4.14 can be adapted to explain the transdisciplinary interoperability execution as shown below in Figure 4.15.

SoS-Interoperability enables relationships among systems:

- Integration enables relationships and ensures synergy of the participant systems- syntactic and semantic interoperability
- Unifies the participant systems to achieve desired holistic behavior
- Syntactic-ability to exchange data
- Semantic-ability to use and understand the data

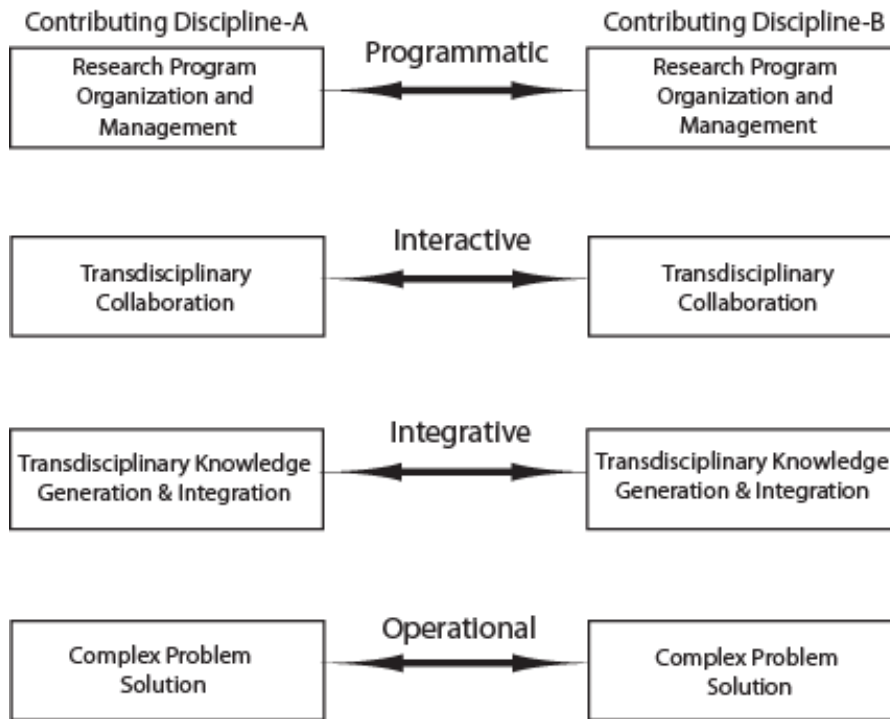


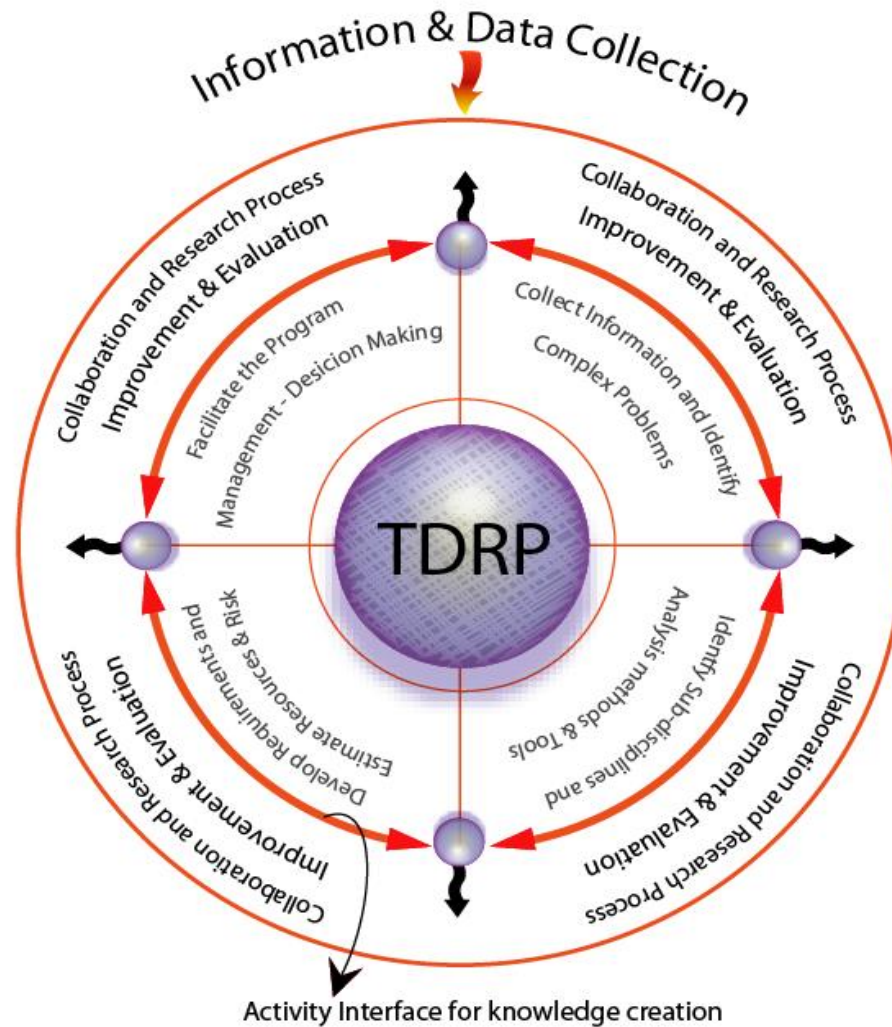
Figure 4.15 Transdisciplinary Interoperability Execution

Transdisciplinary Interoperability enables relationships among disciplines (adapted from reference [172])

- Integration enables relationships and ensures synergy of the participant disciplines-syntactic and semantic interoperability
- Unifies the participant disciplines to achieve desired holistic behavior
- Syntactic-ability to exchange data among the diverse disciplines
- Semantic-ability to use and understand the data among the diverse disciplines (shared concepts, methods and tools)

4.6.4 Generic Activity based Transdisciplinary Research Process

Figure 4.13 can be expanded to develop a Generic Activity based Transdisciplinary Research Process framework as shown below in Figure 4.16.



Generic Activity Based Transdisciplinary Research Process

Figure 4.16 [from reference 133].

In the transdisciplinary research, activity interface is the heart of the process. The key research arm of the TD-RP must be carefully developed. In other words, identify:

- Research fellows: identifies the research experts
- Field researchers: identifies research problem
- Facility based researchers: brings knowledge and resources

- Key team to resolve issues

For successful TD-RP, there is a need for:

- Strong leadership and commitment
- Expertise and effective process and control
- A culture to survive and be effective
- Bi-directional collaboration
- Trust and information flow between researchers

Requirements of transdisciplinary research process can be summarized as:

- Correct information which leads to a research need
- Information storage and availability
- Information processing and analysis for transdisciplinary knowledge generation (shared concepts, methods and tools required for transdisciplinary research)
- Interconnectivity and communication among the researchers from different disciplines

In transdisciplinary activities, depending on the nature of the research and education, some of the disciplines from FOD mentioned in section 4.6.1 will interact by exchanging and sharing:

- Information
- Resources

- Expertise

It is clear technology like the World Wide Web can significantly enhance exchanging and sharing of information, resources, and expertise among the researchers from different disciplines working together to solve common problem(s). TD-RP must be performed rigorously and evaluate issues relating to the research problem through an iterative process. Research process improvement through iterative process allows the researcher to gradually broaden the research scope and in consequence add generality to the research findings.

A central principle of transdisciplinarity is that the researchers from diverse disciplines can best foster the capture and exchange of information and knowledge through a community of transdisciplinary practice: professional networks that identify regional or domestic complex problems collaborate, share concepts, approaches and methods, making the results available to others. A community of transdisciplinary practice is a virtual community such as one created by The Academy of Transdisciplinary Learning & Advance Studies (TheATLAS) [173].

The virtual community concept is a central point of collection for issues such as social, political, educational, infrastructure, agricultural, energy, resources, sanitation, health, environmental, or a combination. Problems may appear in any country and through our highly connected civilization adversely affect communities throughout the world. The transdisciplinary (TD) approach assumes all aspects of a region are connected. Transdisciplinarity not only transcends disciplines but also nations. Moreover, this Transdisciplinary-Transnational-Transcultural (T^3) approach looks at a whole group of problems within a region and views the problems as interconnected. Hence, the design of proposed solutions reaches beyond temporary “one-time” fixes to create a broader, more permanent change which improves the daily lives of everyone in the world affected [173].

It is important to note that numerous complexities are involved with this approach. An example would be researchers working together from diverse disciplines are

geographically dispersed. How such scientific research teams within the approach of transdisciplinarity become organized and managed and also address the complexity of collaboration due to diverse view-points is a great challenge. To obtain the desired research outcome, the conceptual framework shown below in Figure 4.17 is proposed. The transdisciplinarity community is made up of researchers of outstanding ability, expertise, and professionalism. Through collaboration with organizations, we share information, resources, and expertise. These tools will enable researchers to raise their level of knowledge and expertise throughout the transdisciplinary community to the mutual benefit of all participants. There are certainly several technical challenges that exist when implementing the transdisciplinary research process.

Some of them are:

- Understanding of research needs
- Establishment of research requirements (dynamically changing requirements increase uncertainty)
- Diverse view-points increase complexity of collaboration (interconnectivity is a major issue)
- Risk to accomplish the research goal increases when the integration of the appropriate disciplines is not established well (the disciplines are irresolute or ill-integrated in these cases)

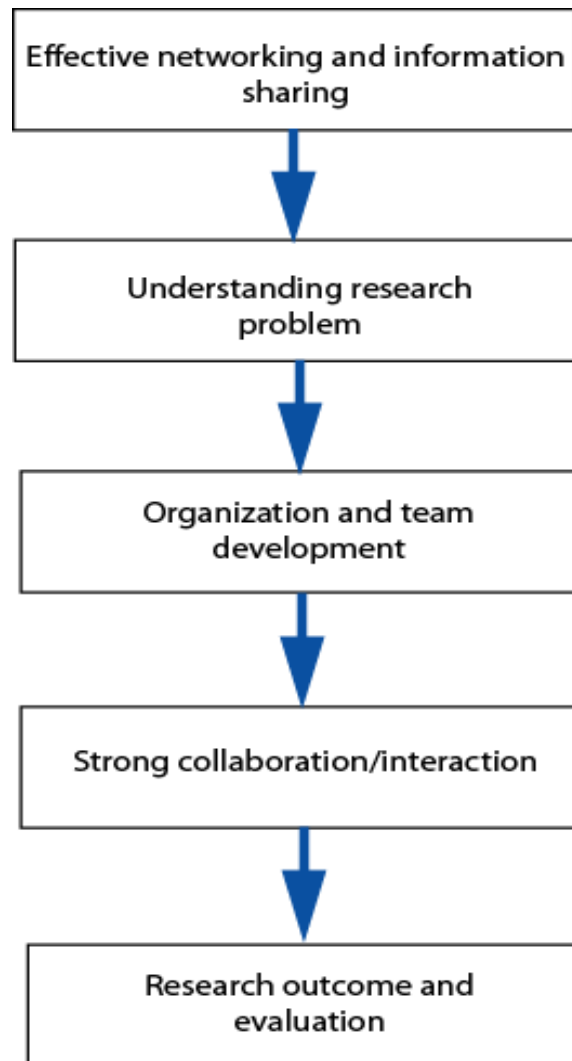


Figure 4.17 Conceptual Framework TD Research Activities

Coping with complexity is the difficult part of the transdisciplinary research process. As mentioned earlier, this process may provide a shared common collection of knowledge to enable us the discovery of new approaches that lead to alternative solutions for the complex problems that face civilization. Structuring complex problems in order to develop better research results in a timely manner is not an easy task. Figure 4.18 below shows a basic framework to understand, evaluate and manage the complexity.

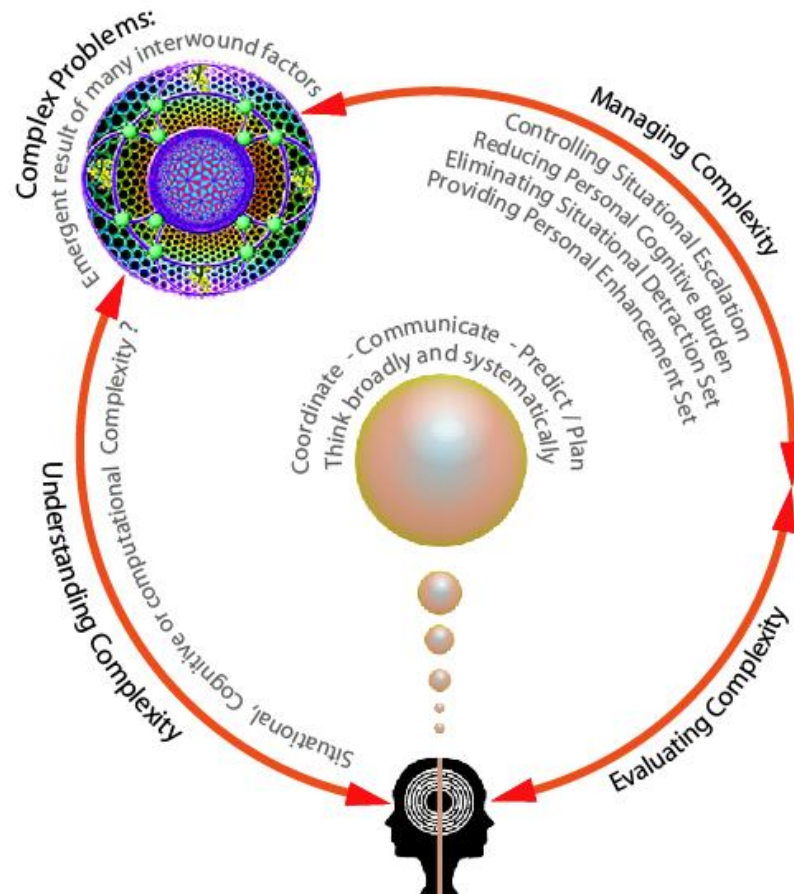


Figure 4.18 Understanding, Evaluating and Managing Complexity [from reference 133].

We can assume that there are two kinds of complexity. Detail Complexity is when there are many variables involved. Dynamic Complexity is situations where cause and effect are difficult to explain, and where the effects over time of interventions are not obvious [174].

Although many definitions have been proposed by researchers, complexity is very difficult to define. In general, these definitions are only applicable to a very restricted domain. However, there is a common, "objective" core in the different concepts of complexity. The original Latin word *complexus*, which signifies "entwined", "twisted together"; could be interpreted in the following way: in order to have a complex you need two or more components which are joined in such a way that it is difficult to separate them [175].

Warfield defined the complexity as frustration experienced by a human being when confronted with a problematic situation that is not understood. It is crucial to understand what generates the complexity. The main sources of frustration could be: language is inadequate to describe the complete view of the frustration, the problematic situation cannot be described, and/or the problematic situation cannot be resolved [176].

Warfield further defined complexity, “one may speak of situational complexity as those aspects of phenomena that are open to being intercepted by the mind and cognitive complexity as those aspects of noumena that make interpretation difficult.” Until the human mind begins to focus upon a problematic situation, cognitive complexity doesn’t come into play. When the mind does become involved with the complex situation, it is more likely that complexity will escalate [177]. We want to learn to think differently and creatively about complex issues and find ways to manage them effectively. It is crucial to understand the complexity in order to manage it.

Warfield considers following four approaches for managing complexity [177]:

- Control of situational escalation
- Reducing personal cognitive burden
- Eliminating the situational detraction set
- Providing the personal enhancement set

For more information about the management of complexity, readers may refer to reference [177].

CHAPTER 5

SURVEY DESIGN, DEVELOPMENT AND ANALYSIS

5.1 Introduction

The goal of this chapter is to present survey design, development, and the use of statistical analysis to evaluate and compare the methodologies of multidisciplinary, interdisciplinary and transdisciplinary research and educational performances [178], [179], [180], and [181].

5.2 Survey Design and Development

Surveys are an effective tool for gathering information to assist in evaluation of research and services. Designing and developing a good questionnaire is the most important and difficult aspect of conducting a survey since there is considerable art that goes into writing a survey questionnaire. Good judgment is all essential for writing questionnaires that are unbiased, valid, and reliable. [182] Creating well-structured questions will be very helpful in collecting valid survey responses. Direct clear questions and answers using the language that survey participants will understand is an important task. While there are no specific rules on creating these survey questions, there are some basic principles that do work to improve the overall survey design.

Relevancy and accuracy are two ideals that encompass the reasonably correct outcome of creating reliable surveys. These two main principles interchangeably work together to write desirable survey questions. As shown in Figure 5.1, to achieve relevancy, one should keep the following factors in mind [183].

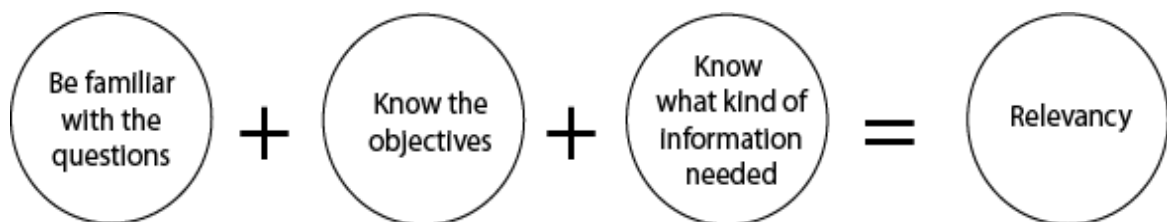


Figure 5.1 Steps to Achieve Relevancy (adapted from reference) [183]

Objectives shown in the figure should be turned into a set of information requirements. Then, one can create questions that will produce meaningful information to satisfy the objectives of the survey.

A reasonably accurate survey is one where the questions collect the data in a reliable and valid way. Namely, respondents should understand the questions and be able to answer the questions. If the questions ask respondents things they do not know, then it can result in inaccurate data [183]. Note that every question should refer back to the objectives.

The key steps for effective survey design include the following steps:

- Define the objectives of the survey
- Select survey methodology
- Decide on the target audience and sample
- Create the relevant questions
- Design and develop the survey process
- Develop and pilot the survey document
- Collect and compile the data
- Analyze the data

Through survey design anyone can toss questions at a respondent, but it is known that creating a meaningful questionnaire takes planning and knowledge. When designing and developing a survey questionnaire, one should ensure that:

1. A survey is in fact the best solution for your need
2. The questions on the survey will drive action for your need
3. The questions are direct and easy to understand for your respondents
4. Your respondents will feel their answers are important to you

The intent is not to just do a survey. Relevant questions should be posed to accomplish your objectives in a smart way; then close the loop, and connect with your respondents.

5.2.1 Types of Survey Questions

It is important to ask the relevant questions in the evaluation process. There are two basic types of survey questions from which to choose: open-ended and closed-ended.

Open-ended questions do not have one definite answer. Although the responses to open-ended questions provide the most detail, they are more difficult to catalogue and interpret.

Example:

Why transdisciplinary research approach is important to solve social complex problems?

Closed-ended questions have a finite set of answers from which the respondent chooses. The disadvantages of closed-ended questions are that they are more difficult to write than open-ended questions [184]. Some of the closed-ended questions examples are given below:

Multiple-choice: Multiple-choice questions are used when we want respondents to pick the best answer. Example:

Why don't researchers use the transdisciplinary research process? (Circle one) It is a new concept

- a) Difficult to use
- b) Complex to manage
- c) Other (please explain)

Rank or Ordinal: questions are ranked according to a level of importance.

Example: Please rank the items from 1 to 5 according to which approach is most important for complex research problem solution. Place a 1 next to the item that is least important and place a 5 next to the item that is most important.

-----Disciplinary approach

-----Multidisciplinary approach

-----Interdisciplinary approach

-----Transdisciplinary approach

Matrix and Rating: These types of questions are used when surveying the frequency of something such as behavior or attitude.

Example: Transdisciplinary research process is an effective approach to solve complex problems.

Strongly Disagree

1

2

3

4

5

Strongly Agree

5.2.2 How to Develop a Good Survey Questionnaire

These sixteen steps will assist you in developing a good survey [185]:

- Questionnaire should be as short as possible
- Use simple words
- Use simple language
- Relax your grammar
- Assure a common understanding
- Write the questions so that everyone will understand in the same way
- Start the survey with questions that are likely to sound interesting and attract the respondents' attention

- Do not write leading questions. For example: the question "Which day of the month is best for the newly established company-wide monthly meeting?" leads respondents to pick a date without first determining if they even want another meeting
- Avoid double negatives
- Balance rating scales by mediating the scale so that there is room for both extremes
- Do not make the list of choices too long
- Avoid questions involving concepts that are difficult for many people to understand
- Avoid difficult recall questions
- Use closed-ended questions rather than open-ended ones
- Put your questions in a logical order
- Pre-test your survey to allow you to learn where your survey instrument may need redesign. Before sending a survey to a target audience, send it out as a test to a small number of people to identify the problems and errors in the survey.

5.2.3 Guidelines for Selecting Target Audience and Sample

- Pick someone who is knowledgeable about the survey objectives, and is articulate enough to share that knowledge
- Be sure you have talked to a mix of people - people of different ages, ethnic backgrounds, religious affiliation, educational level, etc

5.2.4 Survey Response Rate

A survey's response rate represents the number of people actually interviewed as a percentage of the total number of people originally sampled. Depending on the nature of the survey, different kinds of surveys achieve different response rates. The most rigorous surveys conducted in the private and non-profit organizations generally achieve response

rates in the range of 60 percent to 70 percent. Achieving response rates between 40 percent and 50 percent are common [186].

5.3 Statistical Survey Analysis

In this section, statistical tests will be presented to determine the statistical significance of the survey results based on the appropriate sampling distribution. It should be noted that the sample should not contain a systematic bias so that the sample will represent the population drawn from it (American Statistical Association Guides).

In this research the following statistical parameters and analyses will be used [187].

5.3.1 Statistical Parameters

Mean

The mean is defined as the sum of all of the values of the random sample variables x_i , divided by the size of the random sample n , that is,

$$\bar{x} = \frac{\sum_{i=1}^n x_i}{n} \quad (1)$$

Deviation of the data from the mean

Deviation of the mean is the mean of the absolute values of the deviations from the mean.

The mean deviation can be calculated by using

$$\text{Deviation of the Mean} = \frac{\sum_{i=1}^n |x_i - \bar{x}|}{n} \quad (2)$$

Standard deviation

Although the mean deviation is a useful measure of variability, the standard deviation, which is the most reliable measure of variability, is used in most cases. Standard deviation of a random sample is calculated by:

$$S = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}} \quad (3)$$

Where n is the number of sample and S is the sample standard deviation.

Variance

The square of the standard deviation is another very important quantity known as the variance of a random sample; it shows the spread of the distribution and is calculated by

$$S^2 = \frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1} \quad (4)$$

Standard error of the mean

Standard error of the mean $\sigma_{\bar{x}}$ indicates how close the sample mean is to the population mean and is given as

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}} \quad (5)$$

where σ is the standard deviation of the population.

5.3.2 Statistical Hypothesis Testing

A decision problem in which one of two arguments must be chosen is known as a problem of testing hypotheses. The test of a statistical hypothesis is a procedure that leads to a decision to *reject* or *accept* the hypothesis under consideration. In statistical testing, two hypotheses are set: a null hypothesis (initial), denoted H_0 , is the hypothesis

under test or consideration. The alternative hypothesis is denoted by H_1 . After the observation, if the data prove correct with respect to H_0 , H_0 is accepted. If the data prove false with respect to H_0 , H_0 is rejected. In testing a statistical hypothesis, the following steps are carried out:

1. State the hypothesis. The population mean should be equal to some defined hypothetical value μ_H with a given population standard deviation σ set.
 - Null hypothesis $\Rightarrow H_0 : \mu = \mu_H$
 - Alternative hypothesis $\Rightarrow H_1 : \mu \neq \mu_H$
2. Decide on the level of significance, α
3. Select the sample size n
4. Select the statistic to be used in testing the hypothesis

In this research, two types of hypothesis tests will used.

- Hypothesis test about the mean of a normal distribution when the standard deviation is unknown and the sample size is large ($n > 30$)

$$z_{\bar{x}} = \frac{\bar{x} - \mu_H}{\frac{\sigma}{\sqrt{n}}} \quad (6)$$

- Hypothesis test about the mean of a “t” distribution when the standard deviation is unknown and the sample size is small ($n < 30$)

$$t_{\bar{x}} = \frac{\bar{x} - \mu_H}{\frac{S}{\sqrt{n}}} \quad (7)$$

5.3.3 Confidence Interval Estimation Based on the Difference in Two Means (Variance Unknown)

This 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

$$S_p^2 = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2} \quad (8)$$

In the analysis, topical 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

$$\begin{aligned} (\bar{x}_1 - \bar{x}_2) - t_{\alpha/2, n_1 + n_2 - 2} S_p \sqrt{1/n_1 + 1/n_2} &\leq (\mu_1 - \mu_2) \\ &\leq (\bar{x}_1 - \bar{x}_2) + t_{\alpha/2, n_1 + n_2 - 2} S_p \sqrt{1/n_1 + 1/n_2} \end{aligned} \quad (9)$$

For testing the difference in two means, the test hypothesis just mentioned will be used. If the confidence interval given in Equation (9) includes $(\mu_1 - \mu_2) = 0$, it is concluded that there is no statistical difference at a given level of confidence.

5.3.4 One way of ANOVA - Analysis of Variance

This analysis will be used to determine the relationship between transdisciplinary, interdisciplinary and multidisciplinary research performance. One Way ANOVA can be used to test hypotheses regarding the equality of 3 or more groups.

The basis of ANOVA is the partitioning of the sum of squares into between-groups sum of squares, $SS_{between}$ and within groups, 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:

$$SS_T = SS_Y - C \quad (10)$$

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

$$SS_Y = \sum Y_i^2 \quad (11)$$

where Y_i is the observation

$$C = \frac{T^2}{N} \quad (12)$$

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

Between Group Variation

Sum of squares between-groups, $SS_{between}$ is the variation due to the interaction between the samples between groups given by

$$SS_{between} = \frac{L_1^2 + L_2^2 + L_3^2}{n} - C \quad (13)$$

where L is the sum of observations in each group and n is the number of sample size in each group. Mean Square Between groups, $MS_{between}$ is defined by

$$MS_{between} = \frac{SS_{between}}{V_{between}} \quad (14)$$

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

$$V_{between} = \text{number of groups} - 1 \quad (15)$$

Within Group Variation

Sum of squares within groups, SS_{within} is the variation due to differences within individual samples and given by

$$SS_{within} = SS_T - SS_{between} \quad (16)$$

Mean square within groups, MS_{within} is calculated by

$$MS_{within} = \frac{SS_{within}}{\nu_{within}} \quad (17)$$

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

$$\nu_{within} = (n-1)k \quad (18)$$

or

$$\nu_{within} = N - k \quad (19)$$

Where k is the number of groups under consideration.

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

$$F = \frac{MS_{between}}{MS_{within}} \quad (20)$$

It should be noted that if $F \ll 1$ then it is likely that differences between groups means exist. To test the hypothesis, the F value calculated by Eq (20) is compared with the critical value of F . The Critical value of F_{cr} is determined (from statistical tables) using degree of freedom between groups and the degree of freedom within groups values. If the value of F greater than the value of F_{cr} means 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 groups 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 shows statistically significant, then we carry out a second step.

Step 2. Let us assume that we are particularly interested in whether cross-communication and collaboration, use of shared concepts or appropriate research team composed of researchers from diverse disciplines will improve the speed and quality of research for new discoveries. In this scenario, improving the speed and quality of research for new discoveries is a dependent variable and the three approaches (cross-communication and collaboration--use of shared concepts--appropriate research team composed of researchers from diverse disciplines) are the independent variable. In step 1, the F test value showing statistical significance tells us the three means are not equal. It does not indicate where the significant difference lies. Therefore, in the second step, a post hoc analysis should be performed to know where the inequalities are. A post hoc test is used when we have three or more means to compare. This test provides us the Critical Difference between all possible two means. For this study, Fisher's Protected t-test will be used (can be used for samples having equal n or unequal n). The formula is given by:

$$F_{compare} = \frac{(M_i - M_j)^2}{MS_{within} \left(\frac{1}{n_i} + \frac{1}{n_j} \right)} \quad (21)$$

Where i and j are the groups being compared, and n_i and M_i are the number of observations and the mean of group 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 protected t-test, F_{cr} is found by using $df=1$ for the numerator and df_w for the denominator.

5.4 Definitions

Multidisciplinary Concept:

Multidisciplinary activities involve researchers from various disciplines working essentially independently, each from his/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.

Interdisciplinary Concept:

In interdisciplinary activities, researchers from different disciplines work jointly on common problems by exchanging methods, tools, and concepts among them to find integrated solutions.

Transdisciplinary Knowledge:

A shared, common collection of knowledge by integrating science and engineering principles from diverse disciplinary knowledge cultures (engineering, natural science, social science and humanities) enables the discovery of new approaches in education and research that lead to alternative solutions for the increasingly complex problems that face civilization.

Transdisciplinarity Concept:

The transdisciplinarity concept is a collaborative process of a new way of organized knowledge generation and integration by crossing disciplinary boundaries (engineering, natural science, social science and humanities) for designing and implementing solutions to complex problems around the world.

Integration:

It should be noted that the meaning of the word “integration” used in interdisciplinary and transdisciplinary concepts is not the same. In the transdisciplinary concept integration refers to diverse knowledge cultures (engineering, natural science, social science and humanities) that are bridged and fused together to be used for a research problem solution. Integration in the transdisciplinary concept needs to lead to the development of new common shared methods, concepts, and theory and finally to new knowledge [188].

The meaning of an integrated solution, as used in the interdisciplinary concept, is the contributions of the different disciplines are seamlessly integrated to provide a holistic and more effective solution to a research problem.

Transdisciplinary Research Objectives are:

Null Hypotheses

- To improve the speed and quality of research for new discoveries
- To boost innovation
- To enable the discovery of new approaches in education and research that lead to alternative solutions for the increasingly complex problems that face civilization
- To collaborate and interact in new and more integrated ways to confront the engineering and social changes of the future

Main Factors--Transdisciplinary research process requires:

- Cross communication and collaboration
- Use of shared concepts and methods (knowledge integration from different disciplines)
- Appropriate research team composed of researchers from diverse disciplines

Developing Questions Transdisciplinary Research Process:

Objectives will be called dependent variables and main factors will be called independent variables.

Question-1

Please rank the items from 1 to 5 according to what is most important when looking “**to improve the speed and quality of research for new discoveries.**” Place a 1 next to the item that is least important and place a 5 next to the item that is most important.

- Cross communication and collaboration
- Use of shared concepts and methods (knowledge integration from different disciplines)
- Appropriate research team composed of researchers from diverse disciplines

Question-2

Please rank the items from 1 to 5 according to what is most important when looking “**to boost innovation.**” Place a 1 next to the item that is least important and place a 5 next to the item that is most important.

- Cross communication and collaboration
- Use of shared concepts and methods (knowledge integration from different disciplines)
- Appropriate research team composed of researchers from diverse disciplines

Question-3

Please rank the items from 1 to 5 according to what is most important when looking “**to enable the discovery of new approaches in education and research that lead to alternative solutions for the increasingly complex problems that face civilization.**” Place a 1 next to the item that is least important and place a 5 next to the item that is most important.

- Cross communication and collaboration
- Use of shared concepts and methods (knowledge integration from different disciplines)
- Appropriate research team composed of researchers from diverse disciplines

Question-4

- Please rank the items from 1 to 5 according to what is most important when looking “**to collaborate and interact in new and more integrated ways to confront the engineering and social changes 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.

----Cross communication and collaboration

----Use of shared concepts and methods (knowledge integration from different disciplines)

----Appropriate research team composed of researchers from diverse disciplines

Transdisciplinary Graduate Education Objectives:

Null Hypotheses

- 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 can cut across disciplinary boundaries
- To educate students with the ability of innovation and creation
- To educate students with the ability and habits for productive lifelong learning

Main Factors--Transdisciplinary graduate education process requires:

- Enhancing a transdisciplinary dialogue between disciplinary courses
- Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods
- 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
- Defining a theoretical framework leading to a model for transdisciplinary graduate program

Developing Questions Transdisciplinary Education Process:

Question-5

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
- Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods
- 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
- Defining a theoretical framework leading to a model for transdisciplinary graduate program

Question-6

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
- Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods
- 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
- Defining a theoretical framework leading to a model for transdisciplinary graduate program

Question-7

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
- Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods
- 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

- Defining a theoretical framework leading to a model for transdisciplinary graduate program

Question-8

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
- Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods
- 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
- Defining a theoretical framework leading to a model for transdisciplinary graduate program

Question-9

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
- Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods

- 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
- Defining a theoretical framework leading to a model for transdisciplinary graduate program

Question-10

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
- Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods
- 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
- Defining a theoretical framework leading to a model for transdisciplinary graduate program

5.5 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 5.2, the most commonly used term “Multidisciplinary” has had over 18,000 citations by the year 2006 [189].

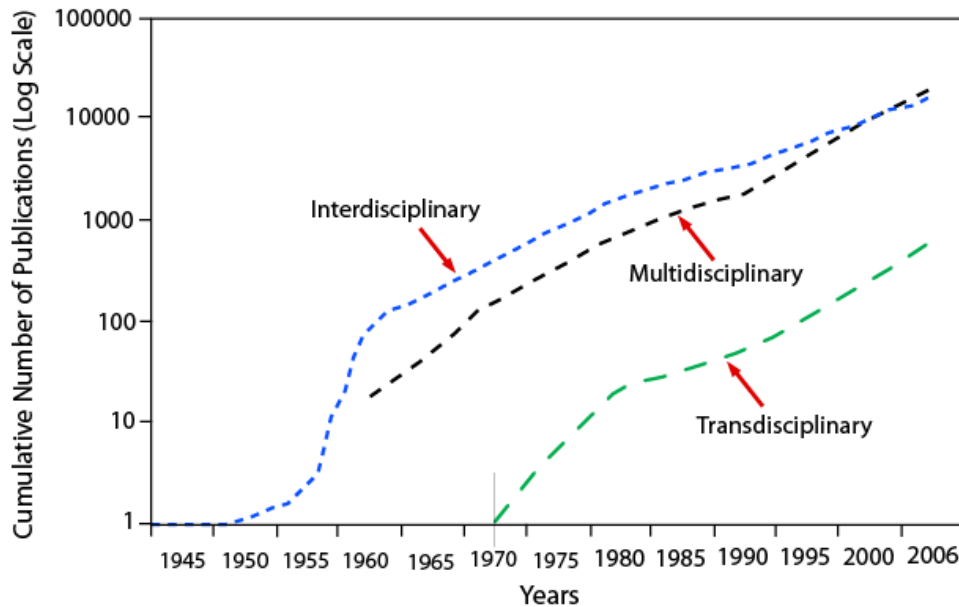


Figure 5.2 Web of Science Citations for Multi-, Inter- and Transdisciplinary Research

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 [190, 191].

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 diverse discipline components [192].

Lawrence compares interdisciplinary research approaches to a “mixing of disciplines,” while transdisciplinary ones would have more to do with a “fusion of disciplines” [193].

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 [194].

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 [194]”.

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. [195]

- **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.
- **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 [196]. Among them: (a) The research budget will be potentially higher since the transdisciplinary research team involves a greater number of researchers; (b) The effort of achieving breadth of analysis and integration may encourage superficial investigation; (c) Bringing together researchers from diverse disciplines to have a collaborative team is an enormous challenge; and (d) 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 [197, 198, 199, 200]. 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 [201].

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

Question-11

To what extent do you think that **Research project organization, managing and coaching are necessary for?** Please circle one

Interdisciplinary research process

Not Very Somewhat Very

Transdisciplinary research process

Not Very Somewhat Very

Question-12

To what extent do you think that **Development of sustained collaboration is necessary for?** Please circle one

Interdisciplinary research process

Not Very Somewhat Very

Transdisciplinary research process

Not Very Somewhat Very

Question-13

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

-----Interdisciplinary research process

-----Transdisciplinary research process

CHAPTER 6

RESULTS AND DISCUSSIONS

6.1 Introduction

A survey on transdisciplinary research and education was conducted starting at 12:01 A.M. on 11 June, 2009 for thirty seven days, ending at Midnight on 17 July, 2009. The survey was divided into four categories (groups). They are researchers, academics, industry/business, and graduates. Texas Tech University 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. These programs have graduated over 120 students. Graduates of these programs were also included in one of the groups in the survey.

With over 134 responses (thank you to all that participated!), the data provides an abundance of useful information on transdiscipline, interdiscipline as well as their research and educational activities. Results of the survey by category (groups) are shown in Table 6.1. 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%.

Table 6.1 Summary of survey responses

Group	# in Group	# of Responses	%	Questions Answered		
				Partial	All	%
Researchers	61	28	45.9%	2	26	42.62%
Academics	75	36	48.0%	3	33	44.00%
Industry/Business	65	48	69.23%	3	42	64.60%
Graduates	40	25	51.9%	1	24	48.00%
Totals	230	134	53.6%	9	125	59.5%

6.2 Relationships of Transdisciplinary Research Objectives to Main Factors for Researcher's, Academic's, Business/Industry and Graduates Categories

Table 6.2 Relationship metric

●	Indicates strong relationship ($4 \leq \text{rating} \leq 5$)
⊙	Indicates medium relationship ($3 \leq \text{rating} < 4$)
○	Indicates weak relationship ($2 \leq \text{rating} < 3$) (less than 2...no relationship)

The general relationship metric used in the analysis is shown in Table 6.2. Figures 6.1-6.4 show the mean values of main factors that the transdisciplinary research process requires for the researchers group (category). Three main factors are:

1. Cross communication and collaboration
2. Use of shared concepts and methods (knowledge integration from different disciplines)
3. Appropriate research team composed of researchers from diverse disciplines

Ranking was used from 1 to 5 least important being 1 and most important being 5. Survey results showed that main factor 2 was rated consistently lower for all the transdisciplinary research objectives by the researchers' category.

Figure 6.5 shows the relationships of transdisciplinary research objectives to main factors for the researchers' category. It is interesting to note that no weak relationship was observed. As stated earlier, main factor 2 showed medium relationship for all the transdisciplinary research objectives.

Figures 6.6-6.9 show the mean values of main factors that the transdisciplinary research process requires for the academic group. All the transdisciplinary research objectives were rated in the neighborhood of 4 or above. This is clearly shown in Figure 6.10 as it indicates strong relationships of transdisciplinary research objectives to main factors for this category.

Figures 6.10-6.14 show the mean values of main factors that transdisciplinary research process requires for the business/industry group. Survey results showed that main factor 2 was rated consistently lower for all the transdisciplinary research objectives by this group. It is interesting to note that same rating was observed by the researchers' category. Relationships of transdisciplinary research objectives to main factors for this category were scattered as shown in Figure 15.

Figures 6.16-6.19 show the mean values of main factors that the transdisciplinary research process requires for the graduates group. Again, main factor 2 was rated consistently lower for all the transdisciplinary research objectives except the transdisciplinary research objective 4 by this group.

As shown in Figures 6.5, 6.10, 6.15 and 6.20, relationships of transdisciplinary research objectives to the first main factor for all categories were strong. In other words, cross communication and collaboration has a strong relationship with all the transdisciplinary research objectives.

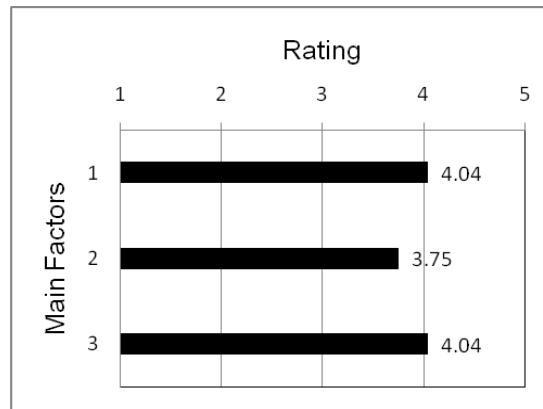


Figure 6.1 Survey Response Summary for Transdisciplinary Research Objective (1),
Group: Researchers

Objective (1): To improve the speed and quality of research for new discoveries. **Main factors:** 1. Cross communication and collaboration; 2. Use of shared concepts and methods (knowledge integration from different disciplines; 3. Appropriate research team composed of researchers from diverse disciplines.

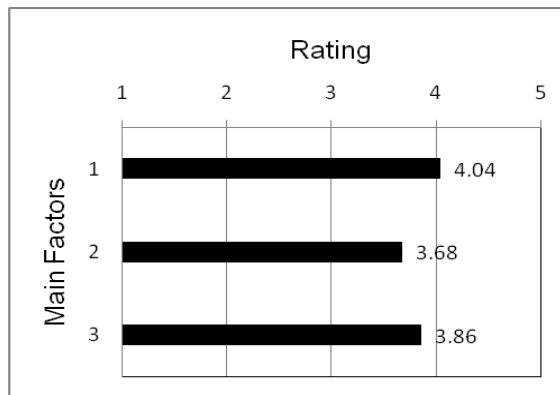


Figure 6.2 Survey Response Summary for Transdisciplinary Research Objective (2),
Group: Researchers

Objective (2): To boost innovation **Main factors:** 1. Cross communication and collaboration; 2. Use of shared concepts and methods (knowledge integration from different disciplines; 3. Appropriate research team composed of researchers from diverse disciplines.

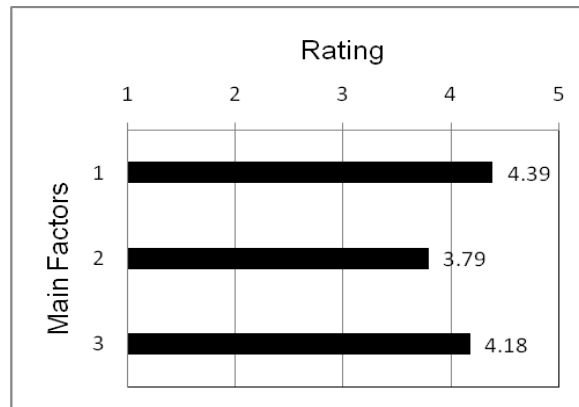


Figure 6.3 Survey Response Summary for Transdisciplinary Research Objective (3),
Group: Researchers

Objective (3): To enable the discovery of new approaches in education and research that lead to alternative solutions for the increasingly complex problems that face civilization.
Main factors: 1. Cross communication and collaboration; 2. Use of shared concepts and methods (knowledge integration from different disciplines; 3. Appropriate research team composed of researchers from diverse disciplines.

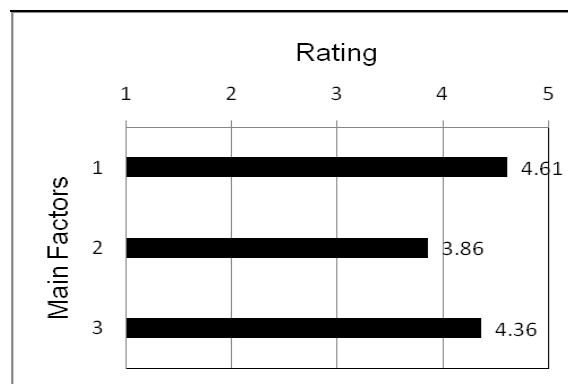


Figure 6.4 Survey Response Summary for Transdisciplinary Research Objective (4),
Group: Researchers

Objective (4): To collaborate and interact in new and more integrated ways to confront the engineering and social changes of the future. **Main factors:** 1. Cross communication and collaboration; 2. Use of shared concepts and methods (knowledge integration from different disciplines; 3. Appropriate research team composed of researchers from diverse disciplines.

Transdisciplinary Research Objectives	Main Factors to Accomplish Objectives		
	1	2	3
To improve the speed and quality of research for new discoveries	●	◎	●
To boost innovation	●	◎	◎
To enable the discovery of new approaches in education and research, that lead to alternative solutions for increasingly complex problems that face civilization	●	◎	●
To collaborate and interact in new and more integrated ways to confront the engineering and social changes of the future	●	◎	●
Main Factors 1. Cross communication and collaboration 2. Use of shared concepts and methods (knowledge integration from different disciplines) 3. Appropriate research team composed of researchers from diverse disciplines Relationship Metric ● Indicates strong relationship ($4 \leq \text{rating} \leq 5$) ◎ Indicates medium relationship ($3 \leq \text{rating} < 4$) ○ Indicates weak relationship ($2 \leq \text{rating} < 3$) (less than 2...no relationship)			

Figure 6.5 Relationship of Transdisciplinary Research Objectives to Main Factors,
Sub-group: Researchers



Figure 6.6 Survey Response Summary for Transdisciplinary Research Objective (1),
Group: Academics

Objective (1): To improve the speed and quality of research for new discoveries. **Main factors:** 1. Cross communication and collaboration; 2. Use of shared concepts and methods (knowledge integration from different disciplines; 3. Appropriate research team composed of researchers from diverse disciplines.

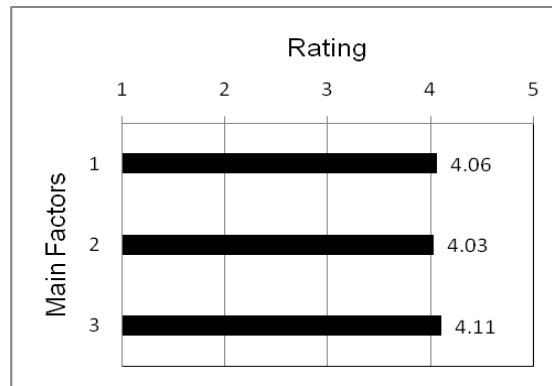


Figure 6.7 Survey Response Summary for Transdisciplinary Research Objective (2),
Group: Academics

Objective (2): To boost innovation. **Main factors:** 1. Cross communication and collaboration; 2. Use of shared concepts and methods (knowledge integration from different disciplines; 3. Appropriate research team composed of researchers from diverse disciplines.

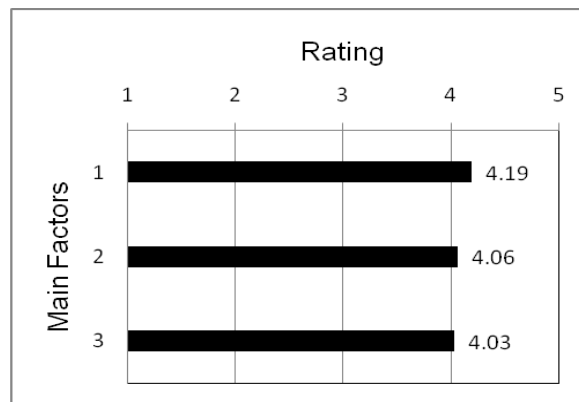


Figure 6.8 Survey Response Summary for
Transdisciplinary Research Objective (3),
Group: Academics

Objective (3): To enable the discovery of new approaches in education and research, that lead to alternative solutions for the increasingly complex problems that face civilization. **Main factors:** 1. Cross communication and collaboration; 2. Use of shared concepts and methods (knowledge integration from different disciplines; 3. Appropriate research team composed of researchers from diverse disciplines.

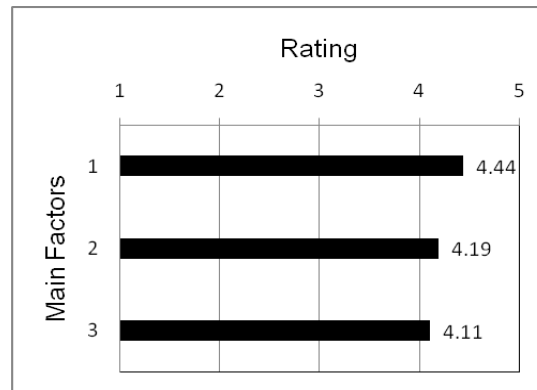


Figure 6.9 Survey Response Summary for Transdisciplinary Research Objective (4),
Group: Academics

Objective (4): To collaborate and interact in new and more integrated ways to confront the engineering and social changes of the future. **Main factors:** 1. Cross communication and collaboration; 2. Use of shared concepts and methods (knowledge integration from different disciplines; 3. Appropriate research team composed of researchers from diverse disciplines.

Transdisciplinary Research Objectives	Main Factors to Accomplish Objectives		
	1	2	3
To improve the speed and quality of research for new discoveries	●	◎	●
To boost innovation	●	●	●
To enable the discovery of new approaches in education and research, that lead to alternative solutions for increasingly complex problems that face civilization	●	●	●
To collaborate and interact in new and more integrated ways to confront the engineering and social changes of the future	●	●	●
Main Factors 1. Cross communication and collaboration 2. Use of shared concepts and methods (knowledge integration from different disciplines) 3. Appropriate research team composed of researchers from diverse disciplines Relationship Metric ● Indicates strong relationship ($4 \leq \text{rating} \leq 5$) ◎ Indicates medium relationship ($3 \leq \text{rating} < 4$) ○ Indicates weak relationship ($2 \leq \text{rating} < 3$) (less than 2....no relationship)			

Figure 6.10 Relationship of Transdisciplinary Research Objectives to Main Factors,
Sub-group: Academics

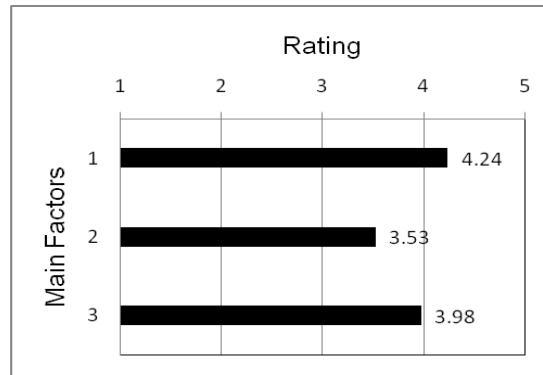


Figure 6.11 Survey Response Summary for Transdisciplinary Research Objective (1),
Group: Business/Industry

Objective (1): To improve the speed and quality of research for new discoveries. **Main factors:** 1. Cross communication and collaboration; 2. Use of shared concepts and methods (knowledge integration from different disciplines; 3. Appropriate research team composed of researchers from diverse disciplines.

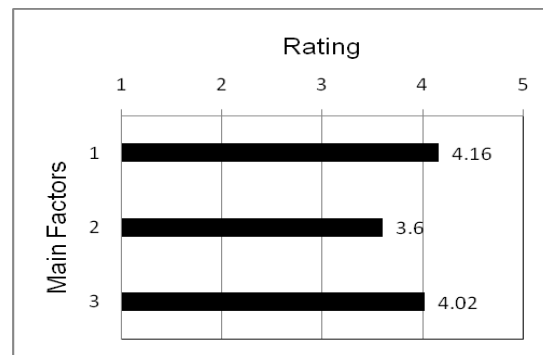


Figure 6.12 Survey Response Summary for Transdisciplinary Research Objective (2),
Group: Business/Industry

Objective (2): To boost innovation. **Main factors:** 1. Cross communication and collaboration; 2. Use of shared concepts and methods (knowledge integration from different disciplines; 3. Appropriate research team composed of researchers from diverse disciplines.



Figure 6.13 Survey Response Summary for Transdisciplinary Research Objective (3),
Group: Business/Industry

Objective (3): To enable the discovery of new approaches in education and research, that lead to alternative solutions for the increasingly complex problems that face civilization. **Main factors:** 1. Cross communication and collaboration; 2. Use of shared concepts and methods (knowledge integration from different disciplines; 3. Appropriate research team composed of researchers from diverse disciplines.



Figure 6.14 Survey Response Summary for Transdisciplinary Research Objective (4),
Group: Business/Industry

Objective (4): To collaborate and interact in new and more integrated ways to confront the engineering and social changes of the future. **Main factors:** 1. Cross communication and collaboration; 2. Use of shared concepts and methods (knowledge integration from different disciplines; 3. Appropriate research team composed of researchers from diverse disciplines.

Transdisciplinary Research Objectives	Main Factors to Accomplish Objectives		
	1	2	3
To improve the speed and quality of research for new discoveries	●	◎	◎
To boost innovation	●	◎	●
To enable the discovery of new approaches in education and research, that lead to alternative solutions for increasingly complex problems that face civilization	●	◎	◎
To collaborate and interact in new and more integrated ways to confront the engineering and social changes of the future	●	◎	◎
Main Factors 1. Cross communication and collaboration 2. Use of shared concepts and methods (knowledge integration from different disciplines) 3. Appropriate research team composed of researchers from diverse disciplines Relationship Metric ● Indicates strong relationship ($4 \leq \text{rating} \leq 5$) ◎ Indicates medium relationship ($3 \leq \text{rating} < 4$) ○ Indicates weak relationship ($2 \leq \text{rating} < 3$) (less than 2...no relationship)			

Figure 6.15 Relationship of Transdisciplinary Research Objectives to Main Factors, Sub-group: Business/Industry

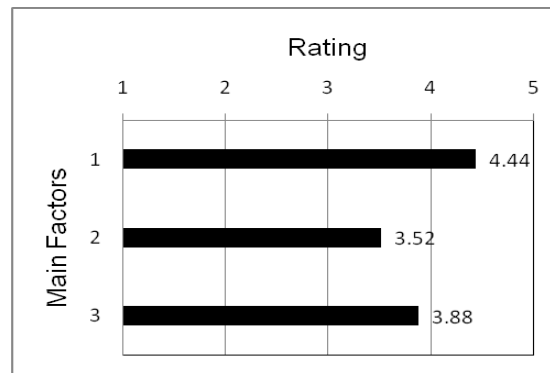


Figure 6.16 Survey Response Summary for Transdisciplinary Research Objective (1), Group: Graduates

Objective (1): To improve the speed and quality of research for new discoveries. **Main factors:** 1. Cross communication and collaboration; 2. Use of shared concepts and methods (knowledge integration from different disciplines; 3. Appropriate research team composed of researchers from diverse disciplines.

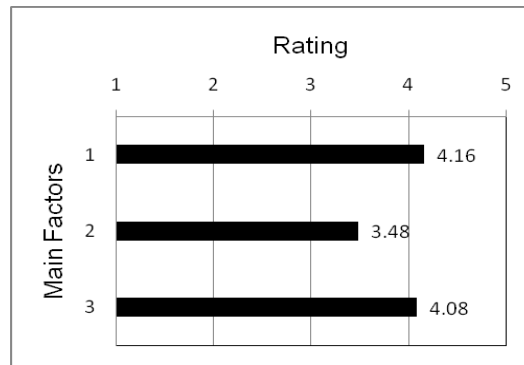


Figure 6.17 Survey Response Summary for Transdisciplinary Research Objective (2),
Group: Graduates

Objective (2): To boost innovation. **Main factors:** 1. Cross communication and collaboration; 2. Use of shared concepts and methods (knowledge integration from different disciplines; 3. Appropriate research team composed of researchers from diverse disciplines.

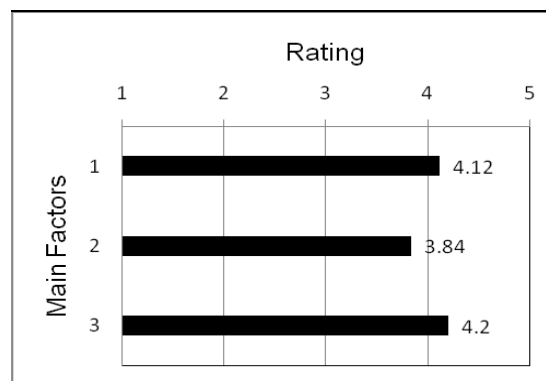


Figure 6.18 Survey Response Summary for Transdisciplinary Research Objective (3),
Group: Graduates

Objective (3): To enable the discovery of new approaches in education and research, that lead to alternative solutions for the increasingly complex problems that face civilization. **Main factors:** 1. Cross communication and collaboration; 2. Use of shared concepts and methods (knowledge integration from different disciplines; 3. Appropriate research team composed of researchers from diverse disciplines.

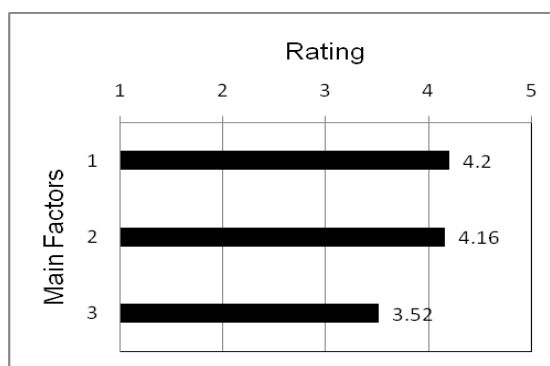


Figure 6.19 Survey Response Summary for Transdisciplinary Research Objective (4),
Group: Graduates

Objective (4): To collaborate and interact in new and more integrated ways to confront the engineering and social changes of the future. **Main factors:** 1. Cross communication and collaboration; 2. Use of shared concepts and methods (knowledge integration from different disciplines; 3. Appropriate research team composed of researchers from diverse disciplines.

Transdisciplinary Research Objectives	Main Factors to Accomplish Objectives		
	1	2	3
To improve the speed and quality of research for new discoveries	●	◎	◎
To boost innovation	●	◎	●
To enable the discovery of new approaches in education and research, that lead to alternative solutions for increasingly complex problems that face civilization	●	◎	●
To collaborate and interact in new and more integrated ways to confront the engineering and social changes of the future	●	●	◎
Main Factors 1. Cross communication and collaboration 2. Use of shared concepts and methods (knowledge integration from different disciplines) 3. Appropriate research team composed of researchers from diverse disciplines Relationship Metric ● Indicates strong relationship ($4 \leq \text{rating} \leq 5$) ◎ Indicates medium relationship ($3 \leq \text{rating} < 4$) ○ Indicates weak relationship ($2 \leq \text{rating} < 3$) (less than 2...no relationship)			

Figure 6.20 Relationship of Transdisciplinary Research Objectives to Main Factors,
Sub-group: Graduates

6.3 Relationships of Transdisciplinary Education Objectives to Main Factors for Researcher's, Academic's, Business/Industry and Graduates Categories

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 *educate students with the ability* of innovation and creation
- To *educate students with the ability and habits for productive lifelong learning*

Main Factors--Transdisciplinary graduate education process requires:

- Enhancing a transdisciplinary dialogue between disciplinary courses
- Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods
- 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
- Defining a theoretical framework leading to a model for transdisciplinary graduate program

Figures 6.21-6.26 show the mean values of main factors that the transdisciplinary education process requires for the researchers group (category). As shown in Figure 6.27, main factor 3 showed very strong relationship with all the education objectives except the second one. Survey results suggest that the objective “*to educate students with the ability and habits for productive lifelong learning,*” *has weak relationship to the main effect of* “Defining a theoretical framework leading to a model for transdisciplinary graduate program.”

Figures 6.28-6.33 show the mean values of main factors that transdisciplinary education process requires for the academics group. As shown in Figure 6.34, main factor 3 showed very strong relationship with all the education objectives except the first one. Survey results revealed that no weak relationship was observed in this category.

Figures 6.35-6.40 show the mean values of main factors that transdisciplinary education process requires for the business/industry group. As shown in Figure 6.41, majority of the relationships were medium. Ranking by the people in this category were below 4 in almost every education objectives with respect to main factors.

Figures 6.42-6.47 show the mean values of main factors that the transdisciplinary education process requires for the graduates group. As shown in Figure 6.48, the majority of the relationships were medium and very scattered. No weak relationship was observed.

So far, we have analyzed the ranking of each group from researchers, academics, business/industry and graduates. Collection of ranking 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 in a combined grouping.

Figures 6.48-6.52 show the mean values of main factors that transdisciplinary research process requires for the entire group. Figure 6.53 represents the relationship of transdisciplinary research objectives with respect to main factors. It is interesting to see that the relationship of transdisciplinary research objectives for the main factor 1 and 2 exactly matches with the researchers groups ranking. Moreover, main factor 3 also shows a similar trend with the exception of main factors 2 and 4 have switched places. Academics group also showed consistency with the entire group results in main factors 1

and 3. Business/industry group showed an exact match in main factors 1 and 2. Majority of the graduate's group decision is consistent with the entire group decision. One thing is for sure; all the groups had the same ranking for main factor 1 for the transdisciplinary research objectives.

Figures 6.54-6.59 show the mean values of main factors that transdisciplinary education requires for the entire group. Figure 6.60 represents the relationship of transdisciplinary education objectives with respect to main factors. As shown in Figure 6.60, relationship is scattered as we have observed in individual group rankings. It is clear that main factor 1 is almost an exact match with all the group's rankings and relationships.

In conclusion, we may say that ideally we discuss the situation, look at it from all sides, evaluating the results. The analyses of the results suggest that individual group decisions are reasonably consistent with the entire group decision.

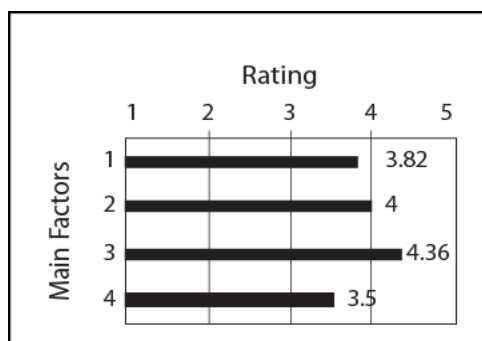


Figure 6.21 Survey Response Summaries for Transdisciplinary Graduate Education
Objective (1), Group: Researchers

Objective (1): To prepare today's students to solve the complex and ill-defined real-world problems of the future. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

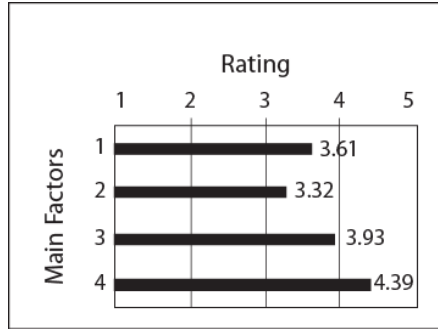


Figure 6.22 Survey Response Summary for Transdisciplinary Graduate Education

Objective (2), Group: Researchers

Objective (2): To educate students broadly and prepare them for an increasingly transdisciplinary, collaborative, and global job market. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

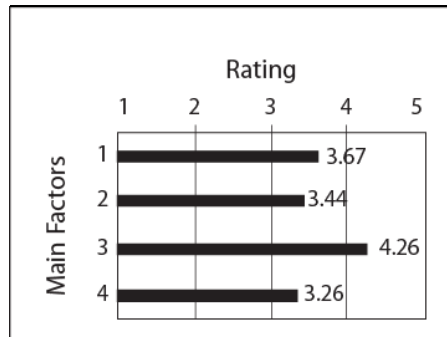


Figure 6.23 Survey Response Summary for Transdisciplinary Graduate Education

Objective (3), Group: Researchers

Objective (3): To prepare students to participate effectively in diverse collaborative organizations. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

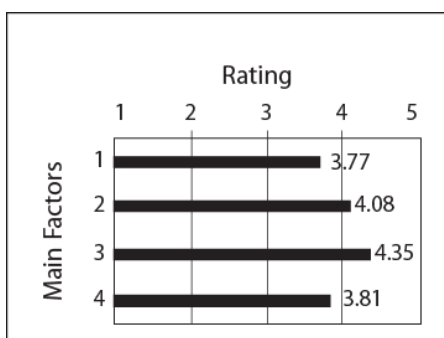


Figure 6.24 Survey Response Summary for Transdisciplinary Graduate Education

Objective (4), Group: Researchers

Objective (4): To provide students with the integrative thinking and skills required to identify, frame and address important practical problems that cut across disciplinary boundaries. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

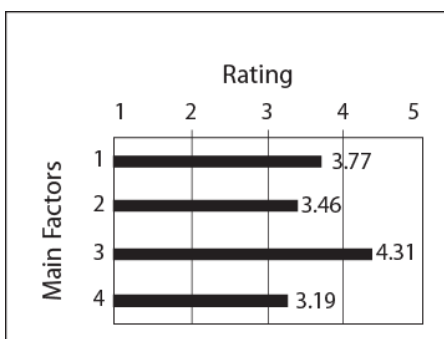


Figure 6.25 Survey Response Summary for Transdisciplinary Graduate Education

Objective (5), Group: Researchers

Objective (5): To educate students with the ability of innovation and creation. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

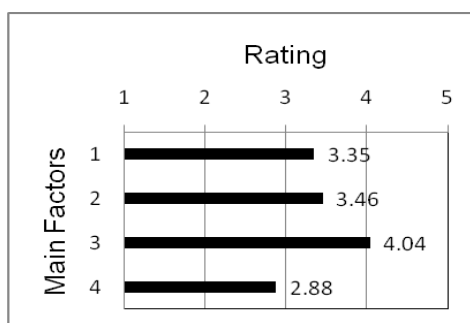


Figure 6.26 Survey Response Summary for Transdisciplinary Graduate Education

Objective (6), Group: Researchers

Objective (6): To educate students with the ability and habits for productive lifelong learning. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

Transdisciplinary Graduate Education Objectives	Main Factors to Accomplish Objectives			
	1	2	3	4
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 educate students with the ability of innovation and creation	●	●	●	●
To educate students with the ability and habits for productive lifelong learning	●	●	●	○
Main Factors 1. Enhancing a transdisciplinary dialogue between disciplinary courses 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods 3. 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 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program Relationship Metric ● Indicates strong relationship ($4 \leq \text{rating} \leq 5$) ● Indicates medium relationship ($3 \leq \text{rating} < 4$) ○ Indicates weak relationship ($2 \leq \text{rating} < 3$) (less than 2...no relationship)				

Figure 6.27 Relationship of Transdisciplinary Graduate Education to Main Factors,

Sub-group: Researchers

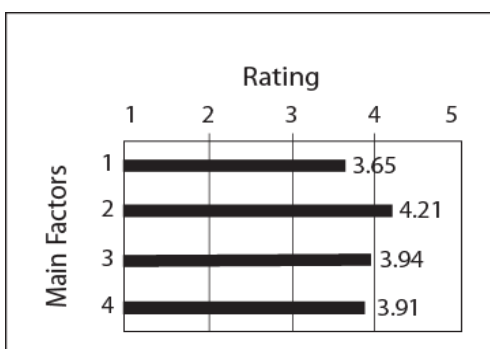


Figure 6.28 Survey Response Summary for Transdisciplinary Graduate Education

Objective (1), Group: Academics

Objective (1): To prepare today's students to solve the complex and ill-defined real-world problems of the future. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.



Figure 6.29 Survey Response Summary for Transdisciplinary Graduate Education

Objective (2), Group: Academics

Objective (2): To educate students broadly and prepare them for an increasingly transdisciplinary, collaborative, and global job market. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

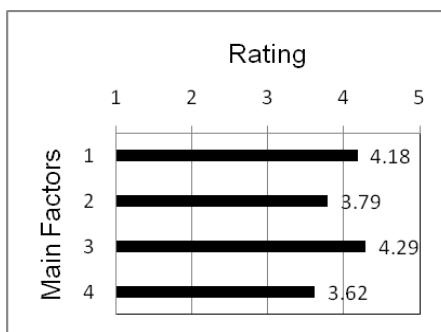


Figure 6.30 Survey Response Summary for Transdisciplinary Graduate Education

Objective (3), Group: Academics

Objective (3): To prepare students to participate effectively in diverse collaborative organizations. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

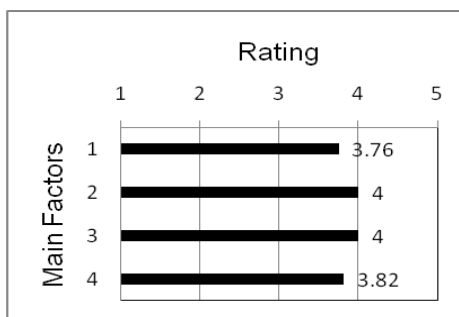


Figure 6.31 Survey Response Summary for Transdisciplinary Graduate Education

Objective (4), Group: Academics

Objective (4): To provide students with the integrative thinking and skills required to identify, frame and address important practical problems that cut across disciplinary boundaries. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

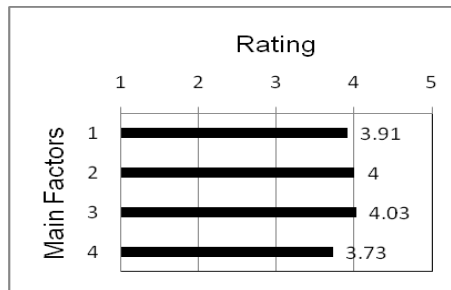


Figure 6.32 Survey Response Summary for Transdisciplinary Graduate Education

Objective (5), Group: Academics

Objective (5): To educate students with the ability of innovation and creation. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

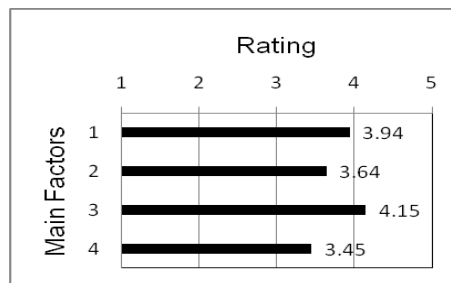


Figure 6.33 Survey Response Summary for Transdisciplinary Graduate Education

Objective (6), Group: Academics

Objective (6): To educate students with the ability and habits for productive lifelong learning. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

Transdisciplinary Graduate Education Objectives	Main Factors to Accomplish Objectives			
	1	2	3	4
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 educate students with the ability of innovation and creation	●	●	●	●
To educate students with the ability and habits for productive lifelong learning	●	●	●	●
Main Factors 1. Enhancing a transdisciplinary dialogue between disciplinary courses 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods 3. 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 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program Relationship Metric ● Indicates strong relationship (4 ≤ rating ≤ 5) ● Indicates medium relationship (3 ≤ rating < 4) ○ Indicates weak relationship (2 ≤ rating < 3) (less than 2...no relationship)				

Figure 6.34 Relationship of Transdisciplinary Graduate Education to Main Factors,
Sub-group: Academics



Figure 6.35 Survey Response Summary for Transdisciplinary Graduate Education
Objective (1), Group: Business/Industry

Objective (1): To prepare today's students to solve the complex and ill-defined real-world problems of the future. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.



Figure 6.36 Survey Response Summary for Transdisciplinary Graduate Education

Objective (2), Group: Business/Industry

Objective (2): To educate students broadly and prepare them for an increasingly transdisciplinary, collaborative, and global job market. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.



Figure 6.37 Survey Response Summary for Transdisciplinary Graduate Education

Objective (3), Group: Business/Industry

Objective (3): To prepare students to participate effectively in diverse collaborative organizations. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

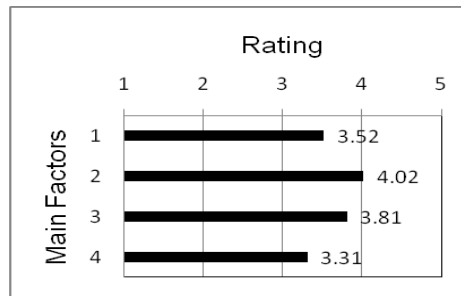


Figure 6.38 Survey Response Summary for Transdisciplinary Graduate Education

Objective (4), Group: Business/Industry

Objective (4): To provide students with the integrative thinking and skills required to identify, frame and address important practical problems that cut across disciplinary boundaries. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

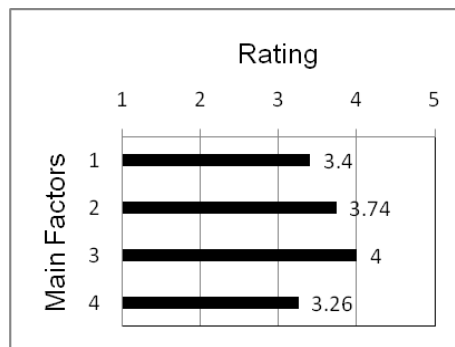


Figure 6.39 Survey Response Summary for Transdisciplinary Graduate Education

Objective (5), Group: Business/Industry

Objective (5): To educate students with the ability of innovation and creation. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.



Figure 6.40 Survey Response Summary for Transdisciplinary Graduate Education
Objective (6), Group: Business/Industry

Objective (6): To educate students with the ability and habits for productive lifelong learning. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

Transdisciplinary Graduate Education Objectives	Main Factors to Accomplish Objectives			
	1	2	3	4
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 educate students with the ability of innovation and creation	●	●	●	●
To educate students with the ability and habits for productive lifelong learning	●	●	●	●
Main Factors 1. Enhancing a transdisciplinary dialogue between disciplinary courses 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods 3. 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 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program Relationship Metric ● Indicates strong relationship (4 ≤ rating ≤ 5) ● Indicates medium relationship (3 ≤ rating < 4) ○ Indicates weak relationship (2 ≤ rating < 3) (less than 2...no relationship)				

Figure 6.41 Relationship of Transdisciplinary Graduate Education to Main Factors,
Sub-group: Business/Industry

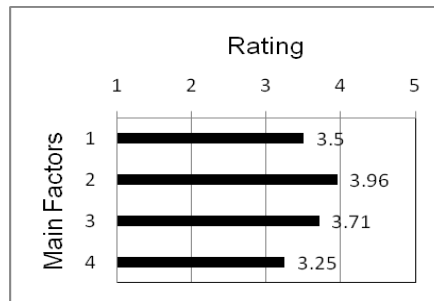


Figure 6.42 Survey Response Summary for Transdisciplinary Graduate Education

Objective (1), Group: Graduates

Objective (1): To prepare today's students to solve the complex and ill-defined real-world problems of the future. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

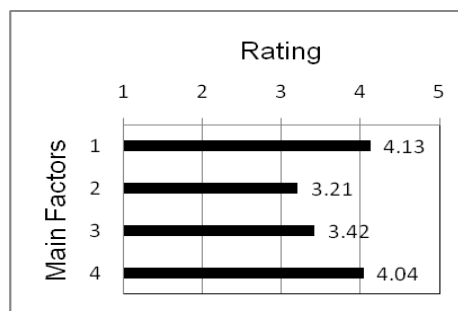


Figure 6.43 Survey Response Summary for Transdisciplinary Graduate Education

Objective (2), Group: Graduates

Objective (2): To educate students broadly and prepare them for an increasingly transdisciplinary, collaborative, and global job market. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

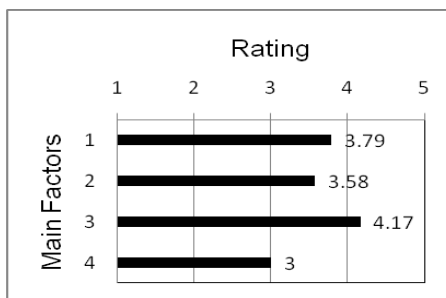


Figure 6.44 Survey Response Summary for Transdisciplinary Graduate Education

Objective (3), Group: Graduates

Objective (3): To prepare students to participate effectively in diverse collaborative organizations. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

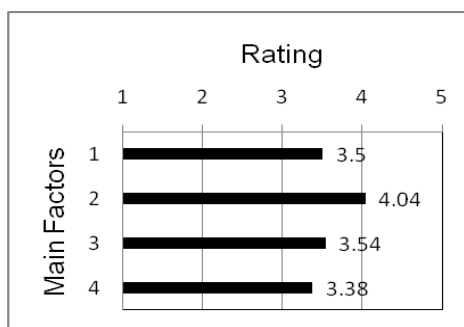


Figure 6.45 Survey Response Summary for Transdisciplinary Graduate Education

Objective (4), Group: Graduates

Objective (4): To provide students with the integrative thinking and skills required to identify, frame and address important practical problems that cut across disciplinary boundaries. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

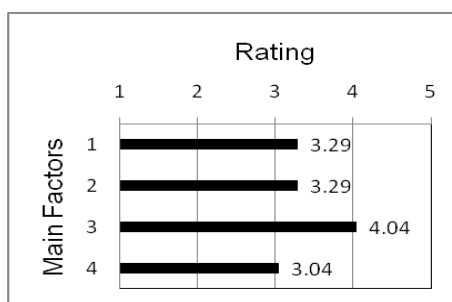


Figure 6.46 Survey Response Summary for Transdisciplinary Graduate Education

Objective (5), Group: Graduates

Objective (5): To educate students with the ability of innovation and creation. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.



Figure 6.47 Survey Response Summary for Transdisciplinary Graduate Education

Objective (6), Group: Graduates

Objective (6): To educate students with the ability and habits for productive lifelong learning. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

Transdisciplinary Graduate Education Objectives	Main Factors to Accomplish Objectives			
	1	2	3	4
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 educate students with the ability of innovation and creation	●	●	●	●
To educate students with the ability and habits for productive lifelong learning	●	●	●	●
Main Factors 1. Enhancing a transdisciplinary dialogue between disciplinary courses 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods 3. 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 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program Relationship Metric ● Indicates strong relationship ($4 \leq \text{rating} \leq 5$) ● Indicates medium relationship ($3 \leq \text{rating} < 4$) ○ Indicates weak relationship ($2 \leq \text{rating} < 3$) (less than 2...no relationship)				

Figure 6.48 Relationship of Transdisciplinary Graduate Education to Main Factors,
Sub-group: Graduates



Figure 6.49 Survey Response Summary for Transdisciplinary Research Objective (1),
Entire Group

Objective (1): To improve the speed and quality of research for new discoveries. **Main factors:** 1. Cross communication and collaboration; 2. Use of shared concepts and methods (knowledge integration from different disciplines; 3. Appropriate research team composed of researchers from diverse disciplines.

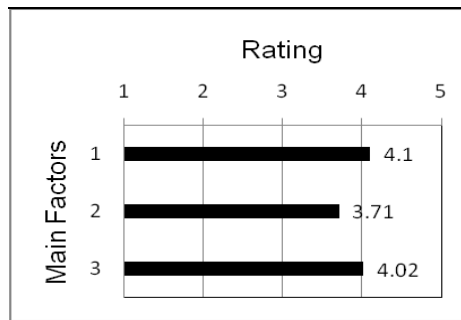


Figure 6.50 Survey Response Summary for Transdisciplinary Research Objective (2),
Entire Group

Objective (2): To boost innovation. **Main factors:** 1. Cross communication and collaboration; 2. Use of shared concepts and methods (knowledge integration from different disciplines; 3. Appropriate research team composed of researchers from diverse disciplines.

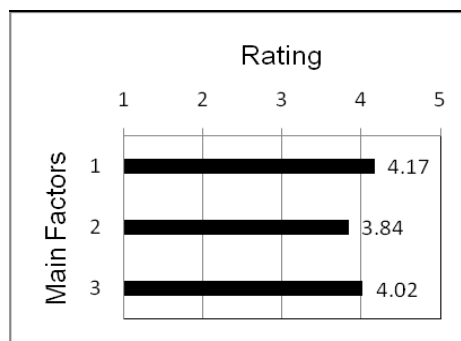


Figure 6.51 Survey Response Summary for Transdisciplinary Research Objective (3),
Entire Group

Objective (3): To enable the discovery of new approaches in education and research, that lead to alternative solutions for the increasingly complex problems that face civilization. **Main factors:** 1. Cross communication and collaboration; 2. Use of shared concepts and methods (knowledge integration from different disciplines; 3. Appropriate research team composed of researchers from diverse disciplines.



Figure 6.52 Survey Response Summary for Transdisciplinary Research Objective (4),
Entire Group

Objective (4): To collaborate and interact in new and more integrated ways to confront the engineering and social changes of the future. **Main factors:** 1. Cross communication and collaboration; 2. Use of shared concepts and methods (knowledge integration from different disciplines; 3. Appropriate research team composed of researchers from diverse disciplines.

Transdisciplinary Research Objectives	Main Factors to Accomplish Objectives		
	1	2	3
To improve the speed and quality of research for new discoveries	●	⊙	●
To boost innovation	●	⊙	●
To enable the discovery of new approaches in education and research, that lead to alternative solutions for increasingly complex problems that face civilization	●	⊙	●
To collaborate and interact in new and more integrated ways to confront the engineering and social changes of the future	●	⊙	⊙
Main Factors 1. Cross communication and collaboration 2. Use of shared concepts and methods (knowledge integration from different disciplines) 3. Appropriate research team composed of researchers from diverse disciplines Relationship Metric ● Indicates strong relationship ($4 \leq \text{rating} \leq 5$) ⊙ Indicates medium relationship ($3 \leq \text{rating} < 4$) ○ Indicates weak relationship ($2 \leq \text{rating} < 3$) (less than 2...no relationship)			

Figure 6.53 Relationship of Transdisciplinary Research Objectives to Main Factors,
Entire Group

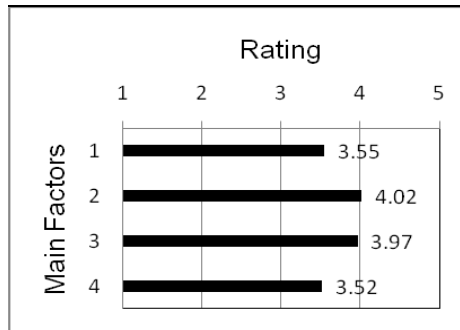


Figure 6.54 Survey Response Summary for Transdisciplinary Graduate Education

Objective (1), Entire Group

Objective (1): To prepare today's students to solve the complex and ill-defined real-world problems of the future. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

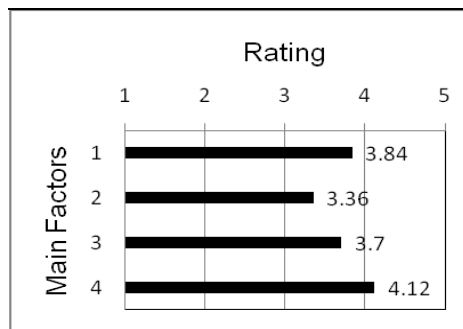


Figure 6.55 Survey Response Summary for Transdisciplinary Graduate Education

Objective (2), Entire Group

Objective (2): To educate students broadly and prepare them for an increasingly transdisciplinary, collaborative, and global job market. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

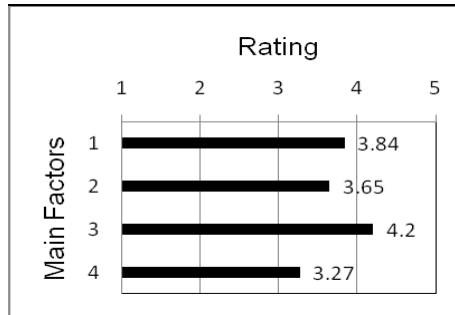


Figure 6.56 Survey Response Summary for Transdisciplinary Graduate Education
Objective (3), Entire Group

Objective (3): To prepare students to participate effectively in diverse collaborative organizations. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

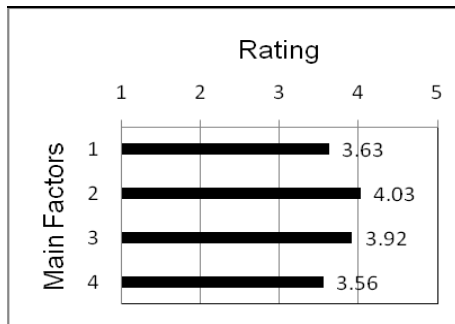


Figure 6.57 Survey Response Summary for Transdisciplinary Graduate Education
Objective (4), Entire Group

Objective (4): To provide students with the integrative thinking and skills required to identify, frame and address important practical problems that cut across disciplinary boundaries. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.



Figure 6.58 Survey Response Summary for Transdisciplinary Graduate Education

Objective (5), Entire Group

Objective (5): To educate students with the ability of innovation and creation. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

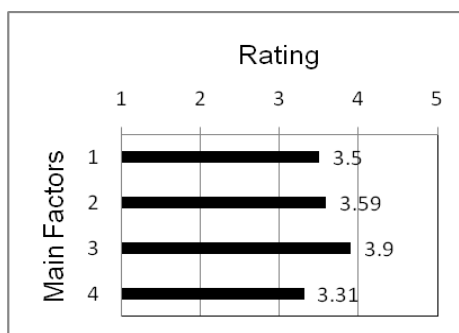


Figure 6.59 Survey Response Summary for Transdisciplinary Graduate Education

Objective (6), Entire Group

Objective (6): To educate students with the ability and habits for productive lifelong learning. **Main factors:** 1. Enhancing a transdisciplinary dialogue between disciplinary courses; 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods; 3. 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; 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program.

Transdisciplinary Graduate Education Objectives	Main Factors to Accomplish Objectives			
	1	2	3	4
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 educate students with the ability of innovation and creation	●	●	●	●
To educate students with the ability and habits for productive lifelong learning	●	●	●	●
Main Factors 1. Enhancing a transdisciplinary dialogue between disciplinary courses 2. Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods 3. 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 4. Defining a theoretical framework leading to a model for transdisciplinary graduate program Relationship Metric ● Indicates strong relationship ($4 \leq \text{rating} \leq 5$) ● Indicates medium relationship ($3 \leq \text{rating} < 4$) ○ Indicates weak relationship ($2 \leq \text{rating} < 3$) (less than 2...no relationship)				

Figure 6.60 Relationship of Transdisciplinary Graduate Education to Main Factors, Entire Group

6.4 One -Way ANOVA

The following assumptions are needed for ANOVA.

- The populations from which the samples are obtained must be approximately normally distributed
- The samples must be independent
- Groups should have approximately equal variance on the dependent variable

We assumed that the populations from which the samples are obtained are approximately normally distributed. ANOVA is a relatively robust procedure with respect to violations of the normality assumption. Assumptions 2 and 3 are satisfied when large sample sizes are used. Assumption 3 is satisfied when the sample sizes are roughly the same for each group. This is true when even small sample sizes are used. In this study, all the sample sizes are same and the sample sizes are reasonably large.

6.4.1 Application of One- Way ANOVA to Researchers Group

a) Transdisciplinary Research Objectives (Group: Researchers)

Transdisciplinary Research Objectives and main factors are:

Null Hypotheses (objectives)

- To improve the speed and quality of research for new discoveries
- To boost innovation
- To enable the discovery of new approaches in education and research, that lead to alternative solutions for the increasingly complex problems that face civilization
- To collaborate and interact in new and more integrated ways to confront the engineering and social changes of the future

Main Factors--Transdisciplinary research process requires:

- Cross communication and collaboration - Treatment A
- Use of shared concepts and methods (knowledge integration from different disciplines) - Treatment B
- Appropriate research team composed of researchers from diverse disciplines - Treatment C

Now considering the first objective:

Suppose we want to test the efficacy of treatments A, B, and C *to improve the speed and quality of research for new discoveries*. In other words, we are interested in whether Treatment A will *improve the speed and quality of research for new discoveries* more than Treatment B or Treatment C.

Hypotheses:

Null: There are no significant differences between the treatments' mean score.

Alternative: There is a significant difference between the treatments' mean score.

For this case, we have 28 samples for each of the three treatments with the survey results shown in Table 6.3 (survey results for all the groups are included in Appendix A from Table 6.1-A to Table 6.58-A). The mean level of *to improve the speed and quality of research for new discoveries* is the dependent variable and Treatments A, B, and C are independent variables. The results of One-Way ANOVA are as follows:

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

$$SS_T = SS_Y - C \quad (22)$$

Where SS_Y = sum of squares of each observation Y and C is the correction factor and given by

$$SS_Y = \sum Y_i^2 = \sum A_i^2 + \sum B_i^2 + \sum C_i^2 = 483 + 409 + 477 = 1369$$

Correction factor C is given by

$$C = \frac{T^2}{N} \quad (23)$$

Where

$T^2 = (113 + 105 + 113)^2 = 109,561$ and, $N = 28 \times 3 = 84$ is the total number of observation.

$$C = \frac{109,561}{84} = 1304.30$$

Table 6.3 Survey result for three treatments A, B, and C

# of Sample	A	B	C
1	4	5	3
2	4	5	4
3	4	3	5
4	3	3	4
5	1	5	3
6	5	4	5
7	4	4	3
8	4	4	4
9	5	2	3
10	4	3	5
11	3	4	3
12	5	4	4
13	4	5	3
14	5	4	5
15	4	4	4
16	4	4	3
17	5	4	4
18	5	3	5
19	5	4	4
20	3	3	3
21	5	4	5
22	4	3	5
23	3	4	5
24	5	3	5
25	5	4	3
26	4	3	5
27	4	3	5
28	2	4	3
<i>SUM</i>	<i>113</i>	<i>105</i>	<i>113</i>
<i>SQUARE</i>	<i>483</i>	<i>409</i>	<i>477</i>
<i>MEAN</i>	<i>4.04</i>	<i>3.75</i>	<i>4.04</i>
<i>SD</i>	<i>1.00</i>	<i>0.75</i>	<i>0.88</i>
<i>SD ERROR</i>	0.19	0.14	0.17

Then

$$SS_T = 1369 - 1304.30 = 64.70$$

The treatment (between subject) sum of squares can be calculated by summing the squared treatment sums, dividing by the number of observations in each sum, and then subtracting the correction factor as:

$$SS_{between} = \left(\frac{113^2}{28} + \frac{105^2}{28} + \frac{113^2}{28} \right) - 1304.30 = 1.52 \quad (24)$$

The within treatment sum is calculated by subtracting the $SS_{between}$ from the SS_T .

$$\begin{aligned} SS_{within} &= SS_T - SS_{between} \\ SS_{within} &= 64.70 - 1.52 = 63.18 \end{aligned} \quad (25)$$

The degrees of freedom associated with each sum of squares are:

For the $SS_{between}$

$$\nu_{between} = \text{number of groups} - 1 = 3 - 1 = 2 \quad (26)$$

For the SS_{within}

k = total number of group members

$$\nu_{within} = N - k = 84 - 3 = 81 \quad (27)$$

For the SS_T

$$\nu_t = \nu_{between} + \nu_{within} = 2 + 81 = 83 \quad (28)$$

Mean Square Between groups, $MS_{between}$ is found by

$$MS_{between} = \frac{SS_{between}}{\nu_{between}} = \frac{1.52}{2} = 0.76 \quad (29)$$

Mean Square Within groups, MS_{within} is calculated by

$$MS_{within} = \frac{SS_{within}}{\nu_{within}} = \frac{63.18}{81} = 0.78 \quad (30)$$

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

$$F = \frac{MS_{between}}{MS_{within}} = \frac{0.76}{0.78} = 0.98 \quad (31)$$

Now, the analysis results can be summarized as shown in Table 6.4.

Table 6.4 Summary of ANOVA table for question #1, Group: Researchers

SOURCE	SS	df	MS	F
Between	1.52	2	0.76	0.98
Within	63.18	81	0.78	
Total	64.70	83		

Assume that the confidence interval is 95%. Then, for a two-tailed critical region with $\frac{\alpha}{2}$ set at 0.025 confidence level and the degree of freedom for $MS_{between}$ being 2 and MS_{within} being 81, the critical value of F_{cr} can be found from F Table as approximately 3.88 (see Appendix B for statistical tables). Since the calculated value $F=0.98$ is smaller than the value $F_{cr}=3.88$, we accept the null. This means that there are no significant differences in three treatments *to improve the speed and quality of research for new discoveries*. They are equally important. In fact, analysis should have been stopped without comparing the critical F value with calculated value. As seen from table 6.2 values of $MS_{between}$ and MS_{within} are almost the same. In this case we would expect the F value be approximately equal to 1. F value is significantly greater than 1 indicates that $MS_{between}$ is greater than the MS_{within} . In this case, we conclude that there is a difference somewhere among the means and it should be investigated further with a *post hoc* test. All the ANOVA results for research group are given in Table 6.5. As seen from the results, the calculated F values for questions 2 and 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 questions 2 and 3. This is shown in Table 6.6.

Table 6.5 Summary of ANOVA tables for *Researchers* group

Question #2

SOURCE	SS	df	MS	F
Between	1.79	2	0.89	0.88
Within	82.50	81	1.02	
Total	84.29	83		

Question #3

SOURCE	SS	df	MS	F
Between	5.31	2	2.65	3.09
Within	69.50	81	0.86	
Total	74.81	83		

Question #4

SOURCE	SS	df	MS	F
Between	8.17	2	4.08	6.54
Within	50.54	81	0.62	
Total	58.70	83		

Question #5

SOURCE	SS	df	MS	F
Between	10.74	3	3.58	4.32
Within	89.54	108	0.83	
Total	100.28	111		

Question #6

SOURCE	SS	df	MS	F
Between	17.74	3	5.91	6.18
Within	103.32	108	0.96	
Total	121.06	111		

Question #7

SOURCE	SS	df	MS	F
Between	15.29	3	5.10	4.38
Within	121.04	104	1.16	
Total	136.32	107		

Question #8

SOURCE	SS	df	MS	F
Between	5.62	3	1.87	1.86
Within	100.38	100	1.00	
Total	106.00	103		

Question #9

SOURCE	SS	df	MS	F
Between	17.88	3	5.96	5.29
Within	112.65	100	1.13	
Total	130.53	103		

Question #10

SOURCE	SS	df	MS	F
Between	17.57	3	5.86	4.58
Within	127.96	100	1.28	
Total	145.53	103		

Question #11

SOURCE	SS	df	MS	F
Between	3.25	1	3.25	5.38
Within	30.19	50	0.60	
Total	33.44	51		

Question #12

SOURCE	SS	df	MS	F
Between	1.56	1	1.56	2.42
Within	32.19	50	0.64	
Total	33.75	51		

Question #13

SOURCE	SS	df	MS	F
Between	3.25	1	3.25	5.64
Within	28.81	50	0.58	
Total	32.06	51		

Table 6.6 Summary of values of F and F_{cr} for *Researchers* group

Question	F	F _{cr}
1	0.98	3.88
2	0.88	3.88
3	3.09	3.88
4	6.54	3.88
5	4.32	3.25
6	6.18	3.25
7	4.38	3.26
8	1.86	3.27
9	5.29	3.27
10	4.58	3.27

Let's consider question 4. Since the degree of freedom is the same as question 1, the value of $F_{cr} = 3.88$ found from F Table remains the same. As shown in Table 6.6, since the calculated value of F is 6.54 is greater than the critical value of $F_{cr} = 3.88$, one must reject the null and conclude that there are significant differences in three treatments *to collaborate and interact in new and more integrated ways to confront the engineering and social changes of the future*. In summary, there are no significant differences in three treatments for the first three transdisciplinary research objectives, whereas for the fourth objective there are significant differences in all three treatments. In this case, the work is not yet over. The calculated significant $F = 6.54$ value obtained in an Analysis of Variance (ANOVA) tells us only that the means are not equal, consequently reject the null hypothesis. To know exactly which means are significantly different from each other, we use *post hoc* tests. There are several types of post hoc tests based on different assumptions and for different purposes. In this research work, *Fisher's protected t-test* will be used.

Now, we use the *Fisher's protected t-test* to understand where the significant difference lies. With three treatments (Treatments A, B and C), the following three comparisons between pairs of means are possible.

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

Calculated *Fisher's protected t-test* values are:

$$\begin{aligned}
 F_{A \times B} &= \frac{(M_A - M_B)^2}{MS_{within} \left(\frac{1}{n_A} + \frac{1}{n_B} \right)} = \frac{(4.61 - 3.86)^2}{0.62 \left(\frac{1}{28} + \frac{1}{28} \right)} = 12.70 \\
 F_{A \times C} &= \frac{(M_A - M_C)^2}{MS_{within} \left(\frac{1}{n_A} + \frac{1}{n_C} \right)} = \frac{(4.61 - 4.36)^2}{0.62 \left(\frac{1}{28} + \frac{1}{28} \right)} = 1.41 \\
 F_{B \times C} &= \frac{(M_B - M_C)^2}{MS_{within} \left(\frac{1}{n_B} + \frac{1}{n_C} \right)} = \frac{(3.86 - 4.36)^2}{0.62 \left(\frac{1}{28} + \frac{1}{28} \right)} = 5.65
 \end{aligned} \tag{32}$$

Hence, comparing above calculated results with the critical $F_{cr}=5.24$ (note that to find the critical value for this case $df=1$ for the numerator and $df_w=81$ for the denominator are used) value, we can conclude that significant difference lies between treatments A and B also between B and C. Since B appears in both pairs, we may further assert that it is the most dominant factor for this case.

B) Transdisciplinary Graduate Objectives (Group: Researchers)

Transdisciplinary Graduate Education Objectives and main factors are:

Null Hypotheses

- 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 *educate students with the ability* of innovation and creation
- To *educate students with the ability and habits for productive lifelong learning*

Main Factors - Transdisciplinary graduate education process requires:

- Enhancing a transdisciplinary dialogue between disciplinary courses
- Creating transdisciplinary fundamental courses which include and implement shared concepts, theories, and methods
- 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
- Defining a theoretical framework leading to a model for transdisciplinary graduate program

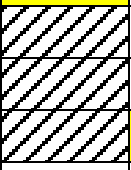
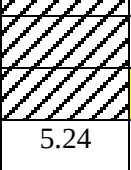
This case covers questions from 5 to 10 and calculated and critical F values are given by Table 6.6. Question 5 corresponds with the first objective of transdisciplinary education with 4 treatments (main factors). They are treatments A, B, C and D. Then question 5

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 degrees of freedom are 3 and 108 (see Table 6.5, question 5), we obtain a 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 5 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.

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

Fisher's Protected t-test results for all the questions under t-test are shown in Table 6.7.

Table 6.7 Calculated Protected t-test Fisher values

Question	4	5	6	7	9	10
A-B	12.70	0.55	1.23	0.62	1.11	0.12
A-C	1.41	4.92	1.49	4.05	3.35	4.84
B-C	5.65	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}	5.24	5.18	5.18	5.19	5.20	5.20

When comparing the critical value of $F_{cr}=5.18$ ($df=1$ for the numerator and $df_w=81$ for the denominator) with the calculated Fisher values, we can say that significant difference lies

only between treatments (C and D) pair, because calculated Fisher value (12.48) is greater than critical value of $F_{cr}=5.18$. In other words, treatment (C and D) pair is significantly different than 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 6, 7, 8, 9 and 10 slightly different, the critical value of F_{cr} will remain in the neighborhood of 5.18. Therefore, with the exception of question #8 (calculated $F=1.86$ is less than critical $F_{cr}=3.27$), all the other questions for this case are statistically significant. Note that (A and B) pair has no significant effect on questions #5, #6, #7 and #9 shown in Table 6.7. (C and D) pair has the significant effect on all the questions except questions #4 and # 6. Table 6.7 reveals that significant difference lies between treatments (A and D), treatments (B and C) and treatments (B and D) for question #6. For question #7 and #9, significant difference lies between treatments (B and C) and treatments (C and D) whereas for question #10 significant difference lies only between treatments (C and D).

c) Interdisciplinary and Transdisciplinary research processes comparison (Group: Researchers)

As stated in Chapter 5, the following items will be considered to compare the interdisciplinary research process with the transdisciplinary research processes.

- Research project organization, managing and coaching
- Development of sustained collaboration
- Quality of integrative research outcome to solve complex problems

Survey Question 11

To what extent do you think that *research project organization, managing and coaching* are necessary for? Rank of “not Very” is 1 and “Very” is 5.

Interdisciplinary research process

Not Very Somewhat Very

Transdisciplinary research process

Not Very Somewhat Very

The survey results are given in Table 6.11-A in the Appendix A. Using values from this table, the pooled estimator can be calculated as

$$S_p^2 = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2} = \frac{(28 - 1)(0.74)^2 + (28 - 1)(0.8)^2}{26 + 26 - 2} = 0.60 \quad (33)$$

Then

$$S_p = 0.776$$

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

$$\begin{aligned} (\bar{x}_1 - \bar{x}_2) - t_{\alpha/2, n_1 + n_2 - 2} S_p \sqrt{1/n_1 + 1/n_2} &\leq (\mu_1 - \mu_2) \\ &\leq (\bar{x}_1 - \bar{x}_2) + t_{\alpha/2, n_1 + n_2 - 2} S_p \sqrt{1/n_1 + 1/n_2} \end{aligned} \quad (34)$$

Substituting values

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

$$\begin{aligned} (\bar{x}_1 - \bar{x}_2) + t_{\alpha/2, n_1 + n_2 - 2} S_p \sqrt{1/n_1 + 1/n_2} \\ = (3.93 - 4.42) + 1.96 \times 0.776 \sqrt{1/26 + 1/26} = -0.078 \\ -0.922 \leq \mu_1 - \mu_2 \leq -0.078 \end{aligned}$$

Note that finding $t_{\alpha/2, n_1 + n_2 - 2} = 1.96$ from the t distribution table (Appendix B) the degree of freedom is taken to be $df = 26 + 26 - 2 = 50$ and $\alpha/2 = 0.025$.

The results above suggest that the confidence interval does not include $(\mu_1 - \mu_2) = 0$, therefore it is concluded that there is statistical difference at the 95% (two sided) level of confidence in two means. By checking means of both research processes, we can conclude that the transdisciplinary research process requires better *research project organization, managing and coaching* than the interdisciplinary research process.

Survey Question 12

To what extent do you think that *development of sustained collaboration* is necessary for?

Rank of “not Very” is 1 and “Very” is 5.

Interdisciplinary research process

Not Very Somewhat Very

Transdisciplinary research process

Not Very Somewhat Very

The survey results are given in Table 6.5-question 12 and Table 6.12-A in the Appendix A.

Using values from aforementioned tables, the result is

$$S_p^2 = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2} = \frac{(28 - 1)(0.8)^2 + (28 - 1)(0.81)^2}{26 + 26 - 2} = 0.647$$

$$S_p = 0.8 \tag{35}$$

$$\begin{aligned} & (\bar{x}_1 - \bar{x}_2) - t_{\alpha/2, n_1 + n_2 - 2} S_p \sqrt{1/n_1 + 1/n_2} \\ & = (4.08 - 4.42) - 1.96 \times 0.8 \sqrt{1/26 + 1/26} = -0.77 \end{aligned}$$

$$\begin{aligned} & (\bar{x}_1 - \bar{x}_2) + t_{\alpha/2, n_1 + n_2 - 2} S_p \sqrt{1/n_1 + 1/n_2} \\ & = (3.93 - 4.42) + 1.96 \times 0.8 \sqrt{1/26 + 1/26} = 0.095 \end{aligned}$$

$$-0.77 \leq \mu_1 - \mu_2 \leq 0.095$$

The above results reveal that the 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 processes and interdisciplinary research process.

Survey Question 13

Please rank the research processes from 1 to 5 when looking *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

The survey results are given in Table 6.5-question 13 and Table 6.13-A in the Appendix A. Using values from aforementioned tables, we have the result as

$$S_p^2 = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2} = \frac{(28 - 1)(0.77)^2 + (28 - 1)(0.75)^2}{26 + 26 - 2} = 0.578$$

$$S_p = 0.76 \quad (36)$$

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

$$= (3.88 - 4.38) - 1.96 \times 0.76 \sqrt{1/26 + 1/26} = -0.913$$

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

$$= (3.88 - 4.38) + 1.96 \times 0.76 \sqrt{1/26 + 1/26} = -0.087$$

$$-0.913 \leq \mu_1 - \mu_2 \leq -0.087$$

The above results suggest that the confidence interval does not includes $(\mu_1 - \mu_2) = 0$, therefore it is concluded that there is a statistical difference at the 95% (two sided) level of confidence in two means. By checking means of both research processes, we can conclude that the transdisciplinary research process provides better *quality of integrative research outcome to solve complex problems* than the interdisciplinary research process.

6.4.2 Application of One-Way ANOVA to Academics Group

For this case, we have 33 samples for each of the three treatments and the survey results are shown in tables in Appendix A (survey results for all the groups are included in Appendix A from Table 6.1-A to Table 6.58-A). The results of One-Way ANOVA are shown in Table 6.8.

Table 6.8 Summary of ANOVA tables for *Academics* group

Question #1

SOURCE	SS	df	MS	F
Between	0.96	2	0.48	0.46
Within	108.89	105	1.04	
Total	109.85			

Question #3

SOURCE	SS	df	MS	F
Between	0.57	2	0.29	0.30
Within	100.50	105	0.96	
Total	101.07			

Question #5

SOURCE	SS	df	MS	F
Between	5.32	3	1.77	1.83
Within	127.94	132	0.97	
Total	133.26			

Question #7

SOURCE	SS	df	MS	F
Between	10.29	3	3.43	3.50
Within	129.59	132	0.98	
Total	139.88			

Question #9

SOURCE	SS	df	MS	F
Between	1.84	3	0.61	0.54
Within	146.24	128	1.14	
Total	148.08			

Question #11

SOURCE	SS	df	MS	F
Between	4.38	1	4.38	5.81
Within	48.24	64	0.75	
Total	52.62			

Question #13

SOURCE	SS	df	MS	F
Between	13.64	1	13.64	20.69
Within	42.18	64	0.66	
Total	55.82			

Question #2

SOURCE	SS	df	MS	F
Between	0.13	2	0.06	0.07
Within	104.42	105	0.99	
Total	109.85			

Question #4

SOURCE	SS	df	MS	F
Between	2.17	2	1.08	1.46
Within	78.08	105	0.74	
Total	80.25			

Question #6

SOURCE	SS	df	MS	F
Between	2.90	3	0.97	1.03
Within	123.91	132	0.94	
Total	126.82			

Question #8

SOURCE	SS	df	MS	F
Between	1.55	3	0.52	0.50
Within	132.97	128	1.04	
Total	134.52			

Question #10

SOURCE	SS	df	MS	F
Between	9.54	3	3.18	2.71
Within	149.94	128	1.17	
Total	159.48			

Question #12

SOURCE	SS	df	MS	F
Between	8.73	1	8.73	11.46
Within	48.73	64	0.76	
Total	57.45			

a) Transdisciplinary Research Objectives (Group: Academics)Table 6.9 Summary of values of F and Fcr for *academics* group

Question	F	Fcr
1	0.46	3.83
2	0.07	3.83
3	0.30	3.83
4	1.46	3.83

As seen in Table 6.9, no question's calculated F values are higher than the critical values of F values. Therefore, we accept the null and conclude that they are not statistically significant. In summary, there are no significant differences in the three treatments for all the transdisciplinary research objectives. In this case, we stop further analysis.

b) Transdisciplinary Education Objectives (Group: Academics)Table 6.10 Summary of values of F and Fcr for *academics* group

Question	F	Fcr
5	1.83	3.21
6	1.03	3.21
7	3.50	3.21
8	0.50	3.21
9	0.54	3.21
10	2.71	3.21

This group covers questions from 5 to 10. As seen from Table 6.10 results of calculated F values for all the questions except question #7 are smaller than the critical F_{cr} values. Hence, we accept the null and conclude that there are no significant differences with regards to questions mentioned. Since question # 7 calculated F value (3.50) is higher than critical value of $F_{cr}=3.21$, we conclude that there is a significant difference regarding this question.

Table 6.11 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
Fcr	5.12

From Table 6.11, when comparing the critical value of $F_{cr} = 5.12$ with the calculated Fisher values, we can say that significant difference lies only between treatments (A and D) and (C and D) pairs because calculated Fisher values are greater than critical value of $F=5.12$. In other words, to prepare students to participate effectively in diverse collaborative organizations (B and C) and (C and D) pair treatments are significantly different than others. The treatment C, which is “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,” is the most dominant main factor.

**c) Interdisciplinary and Transdisciplinary research processes comparison
(Group: Academics)**

Randomly selected 28 sample data were analyzed. The summary of the calculations given in Table 6.12 shows that there is a statistical difference for all three questions mentioned earlier (confidence interval does not include $(\mu_1 - \mu_2) = 0$). Using evaluation of the mean values shown in Table 6.12, we conclude that *research project organization, managing, coaching, and development of sustained collaboration* are more needed for the transdisciplinary research process than the interdisciplinary research process. The mean values of transdisciplinary research process are greater than interdisciplinary research process. (See Table 6.12) Also, survey results suggest that transdisciplinary research process does provide better quality research outcome than the interdisciplinary research process. It is interesting to note that the outcome of the survey results from academic people for question #12 turns out to be different than survey results from researchers groups.

Table 6.12 Summary of calculations for Interdisciplinary and Transdisciplinary research process comparison (Academics)

Questions	S_p	$\leq (\mu_1 - \mu_2) \leq$	$\bar{x}_1$	$\bar{x}_2$
#11	0.87	$-0.92 \leq (\mu_1 - \mu_2) \leq -0.16$	4.14	4.68
#12	0.88	$-1.32 \leq (\mu_1 - \mu_2) \leq -0.40$	3.68	4.54
#13	0.81	$-1.22 \leq (\mu_1 - \mu_2) \leq -0.48$	3.86	4.71

6.4.3 Application of One-Way ANOVA to Business/Industry Group

For this case, we have 36 samples for each of the three treatments and the survey results shown in tables in Appendix A (survey results for all the groups are included in Appendix A from Table 6.1-A to Table 6.58-A). The results of One-Way ANOVA are shown in Table 6.13. Summary of values of F and Fcr for this group are given by Table 6.14 and Calculated Protected t-test Fisher values are given by Table 6.15.

Table 6.13 Summary of ANOVA tables Group: *Business/Industry*

Question #1

SOURCE	SS	df	MS	F
Between	11.61	2	5.81	6.58
Within	116.49	132	0.88	
Total	128.10	134		

Question #2

SOURCE	SS	df	MS	F
Between	7.57	2	3.79	4.39
Within	113.69	132	0.86	
Total	121.26	134		

Question #3

SOURCE	SS	df	MS	F
Between	2.90	2	1.45	1.57
Within	122.13	132	0.93	
Total	125.04	134		

Question #4

SOURCE	SS	df	MS	F
Between	8.90	2	4.45	5.12
Within	114.84	132	0.87	
Total	123.75			

Question #5

SOURCE	SS	df	MS	F
Between	12.90	3	4.30	3.62
Within	199.53	168	1.19	
Total	212.44	171		

Question #6

SOURCE	SS	df	MS	F
Between	18.86	3	6.29	5.54
Within	190.65	168	1.13	
Total	209.51	171		

Question #7

SOURCE	SS	df	MS	F
Between	20.81	3	6.94	5.73
Within	203.30	168	1.21	
Total	224.11	171		

Question #8

SOURCE	SS	df	MS	F
Between	12.43	3	4.14	3.49
Within	194.90	164	1.19	
Total	207.33	167		

Question #9

SOURCE	SS	df	MS	F
Between	13.92	3	4.64	3.62
Within	210.36	164	1.28	
Total	224.28	167		

Question #10

SOURCE	SS	df	MS	F
Between	3.64	3	1.21	0.81
Within	244.21	164	1.49	
Total	247.85	167		

Question #11

SOURCE	SS	df	MS	F
Between	3.05	1	3.05	3.61
Within	69.24	82	0.84	
Total	72.29	83		

Question #12

SOURCE	SS	df	MS	F
Between	7.44	1	7.44	11.04
Within	55.26	82	0.67	
Total	62.70	83		

Question #13

SOURCE	SS	df	MS	F
Between	12.19	1	12.19	22.03
Within	45.38	82	0.55	
Total	57.57	83		

Table 6.14 Summary of values of F and F_{cr} for business/industry group

Question	F	F _{cr}
1	6.58	3.78
2	4.39	3.78
3	1.57	3.78
4	5.12	3.78
5	3.62	3.20
6	5.54	3.20
7	5.73	3.20
8	3.49	3.20
9	3.62	3.20
10	0.81	3.20

Table 6.15 Calculated Protected t -test Fisher values for business/industry group

Question	1	2	4	5	6	7	8	9
A-B	12.89	8.20	7.54	6.08	8.04	0.01	4.41	1.90
A-C	1.73	0.51	8.11	5.47	3.20	2.84	1.48	5.91
B-C	5.18	4.62	0.01	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}	5.13	5.13	5.13	5.10	5.10	5.10	5.08	5.08

a) Transdisciplinary Research Objectives (Group: Business/Industry)

As shown in Table 6.14, questions from 1 to 4 covers transdisciplinary research objectives. Results reveal that except for question 3 the others prove to be statistically significant. As seen from Table 6.15, significant difference for question # 1 lies between treatments (A and B) and treatments (B and C), for question # 2 only (A and B), and for question #4 (A and B) and (A and C).

b) Transdisciplinary Education Objectives (Group: Business/Industry)

As shown in Table 6.14, questions from 5 to 10 covers transdisciplinary education objectives. As shown in Table 6.14, all the questions are statistically significant except question #10. Table 6.15 reveals that significant difference for question # 5 lies between treatments (A and B), (A and C) and (B and D), for question # 6 treatments (A and B), (B and D) and (C and D), for question # 7 treatments (A and D), (B and D) and (C and D), for question # 8 treatment (B and D), and for question #9 for treatments (A and C) and (C and D). In this case, we can say that main factors B and D are the most dominant ones.

c) Interdisciplinary and Transdisciplinary research processes comparison (Group: Business/Industry)

Randomly selected 28 sample data were analyzed. The summary of the calculations given in Table 6.16 shows that there is a statistical difference for all three questions mentioned earlier (confidence interval does not include $(\mu_1 - \mu_2) = 0$). Given the evaluation mean values shown in Table 6.16, we conclude that *research project organization, managing, coaching, and development of sustained collaboration* are more needed for the transdisciplinary research process than the interdisciplinary research process. Also, survey results suggest that transdisciplinary research process does provide better quality research outcome than the interdisciplinary research process. It is interesting to note that the outcome of the survey results from business/industry people turns out to be as same as academic people.

Table 6.16 Summary of calculations for Interdisciplinary and Transdisciplinary research process comparison (Group: Business/Industry)

Questions	S_p	$\leq (\mu_1 - \mu_2) \leq$	$\bar{x}_1$	$\bar{x}_2$
#11	0.93	$-1.02 \leq (\mu_1 - \mu_2) \leq -0.04$	3.79	4.32
#12	0.83	$-1.21 \leq (\mu_1 - \mu_2) \leq -0.35$	3.68	4.46
#13	0.70	$-1.27 \leq (\mu_1 - \mu_2) \leq -0.53$	3.71	4.61

6.4.4 Application of One-Way ANOVA to Graduates Group

For this case, we have 25 samples for each of the three treatments and the survey results are shown in tables in Appendix A (survey results for all the groups are included in Appendix A from Table 6.1-A to Table 6.58-A). The results of One-Way ANOVA are shown in Table 6.17. The summaries of values of F and Fcr for this group are given by Table 6.18 and the Calculated Protected t-test Fisher values are given by Table 6.19.

Table 6.17 Summary of ANOVA tables Group: *Graduates*

Question #1

SOURCE	SS	df	MS	F
Between	10.75	2	5.37	5.60
Within	69.04	72	0.96	
Total	79.79	74		

Question #2

SOURCE	SS	df	MS	F
Between	6.91	2	3.45	2.98
Within	83.44	72	1.16	
Total	90.35	74		

Question #3

SOURCE	SS	df	MS	F
Between	1.79	2	0.89	0.87
Within	74.00	72	1.03	
Total	75.79	74		

Question #4

SOURCE	SS	df	MS	F
Between	7.28	2	3.64	3.56
Within	73.60	72	1.02	
Total	80.88	74		

Question #5

SOURCE	SS	df	MS	F
Between	6.54	3	2.18	1.64
Within	122.42	92	1.33	
Total	128.96	95		

Question #6

SOURCE	SS	df	MS	F
Between	14.86	3	4.95	4.41
Within	103.38	92	1.12	
Total	118.24	95		

Question #7

SOURCE	SS	df	MS	F
Between	17.11	3	5.70	4.99
Within	105.13	92	1.14	
Total	122.24	95		

Question #8

SOURCE	SS	df	MS	F
Between	6.20	3	2.07	1.66
Within	114.54	92	1.25	
Total	120.74	95		

Question #9

SOURCE	SS	df	MS	F
Between	13.50	3	4.50	3.29
Within	125.83	92	1.37	
Total	139.33	95		

Question #10

SOURCE	SS	df	MS	F
Between	4.42	3	1.47	0.97
Within	140.08	92	1.52	
Total	144.50	95		

Question #11

SOURCE	SS	df	MS	F
Between	6.75	1	6.75	10.99
Within	28.25	46	0.61	
Total	35.00	47		

Question #12

SOURCE	SS	df	MS	F
Between	7.52	1	7.52	17.48
Within	19.79	46	0.43	
Total	27.31	47		

Question #13

SOURCE	SS	df	MS	F
Between	6.75	1	6.75	10.18
Within	30.50	46	0.66	
Total	37.25	47		

Table 6.18 Summary of values of F and Fcr for Graduates group

Question	F	Fcr
1	5.60	3.90
2	2.98	3.90
3	0.87	3.90
4	3.56	3.90
5	1.64	3.28
6	4.41	3.28
7	4.99	3.28
8	1.66	3.28
9	3.29	3.28
10	0.97	3.28

Table 6.19 Calculated Protected t-test Fisher values for Graduates Group

Question	1	6	7	9
A-B	11.02	9.07	0.46	0.00
A-C	4.08	5.40	1.52	4.93
B-C	1.69	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
Fcr	5.26	5.22	5.22	5.22

a) Transdisciplinary Research Objectives (Group: Graduates)

As shown in Table 6.18, questions from 1 to 4 covers transdisciplinary research objectives. Results reveal that only question #1 is statistically significant. As seen from Table 6.19, a significant difference for question # 1 lies between treatments (A and B).

b) Transdisciplinary Education Objectives (Group: Graduates)

As shown in Table 6.18, questions from 5 to 10 covers transdisciplinary education objectives. As shown in Table 6.19, questions #6, #7 and # 9 are statistically significant. Table 6.19 reveals that the significant difference for question # 6 lies between treatments (A and B), (A and C) and (B and D), for question # 7 treatments (A and D), (C and D), for question # 9 only treatment (C and D). In this case we can say that the main factor D is the most dominant one.

c) Transdisciplinary research processes comparison (Group: Graduates)

Using 25 sample data, a summary of the calculations is given in Table 6.20 showing that there is a statistical difference for all three questions mentioned earlier (confidence interval doesn't include $(\mu_1 - \mu_2) = 0$). An evaluation of the mean values shown in Table 6.20 suggest that the *research project organization, managing, coaching, and development of sustained collaboration* are more needed for the transdisciplinary research process than the interdisciplinary research process. Also, survey results suggest that transdisciplinary research process does provide better quality research outcome than the interdisciplinary research process.

Table 6.20 Summary of calculations for Interdisciplinary and Transdisciplinary research process comparison (Group: Graduates)

Questions	S_p	$\leq (\mu_1 - \mu_2) \leq$	$\bar{x}_1$	$\bar{x}_2$
#11	0.79	$-1.19 \leq (\mu_1 - \mu_2) \leq -0.31$	3.88	4.63
#12	0.65	$-1.94 \leq (\mu_1 - \mu_2) \leq -0.43$	3.79	4.58
#13	0.81	$-1.20 \leq (\mu_1 - \mu_2) \leq -0.30$	3.75	4.50

6.5 Relationship Analysis Conclusion:

- a) This research has determined the need for a good framework to be used with transdisciplinary research.
- b) The research gained in producing and conducting the survey gave us a viable and positive return through the responses of the participants.
- c) This has convinced us that we will continue to move forward with the Transdisciplinary Research Process (TD-RP) based on ex[anding the System of Systems (SoS) framework.

CHAPTER 7

RECOMMENDATIONS AND CONCLUSIONS

7.1 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 [202]. 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.

7.2 Defining the Challenge

All over the world universities are working to change their visions of education and research. Ten years 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. Four years ago they introduced the Ph.D program in Transdisciplinary Design, Process and Systems. Raytheon, a large U.S. defense contractor, is a prime supporter of the program. To date well over 100 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 don't 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 [203]. 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 [204].

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.

7.3 Survey Discussion

In researching this dissertation we came up with several items that we felt very strongly about and decided that we needed some added support to reinforce these decisions. The first decision was to conduct a survey. The next decision was to select the participants based on background and knowledge. The desire was that they would be knowledgeable about the subject matter of the survey based on their experience in the fields of inquiry and research. With these decisions being made the survey was put together. We applied for authorization through the Texas Tech University Research Services and received our letter of exemption for the survey on 6-10-2009.

A survey on interdisciplinary and transdisciplinary research and education was conducted starting with the release at 2:00 AM on June 11 and ran until July 17 at 11:59 PM. No more results were added after the deadline. 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.

The data provided an abundance of useful information on transdiscipline, interdiscipline as well as their research and educational activities. Results of the survey by groups are shown in Table 6.1. Most of the results were about what we expected, and only a very few of them surprised us. The rate of response for the survey was better than expected. 250 surveys were sent out to valid email sites and the responses totaled 134. Total

response rate was 53.6%, while in every category the response rates reached to at least 45.9%.

The survey results suggest that the research project organization, managing, coaching and development of sustained collaboration are more needed for the transdisciplinary research process than the interdisciplinary research process. Also survey results suggest that the transdisciplinary research process provides a better quality research outcome than the interdisciplinary research process. It is interesting to note that the outcome of the survey results from academics, business/industry, and graduates turn out to be exactly the same.

7.4 Conclusions, Contributions and Recommendations

This research has determined the need for a good framework to be used with transdisciplinary research. The research we gained in producing and conducting the survey gave a viable and positive return through the responses of the participants. This has convinced us that we will continue to move forward with the Transdisciplinary Research Process (TD-RP) based on expanding the Systems of Systems (SoS) framework.

It is interesting to note that engineering has not been included as a key part of the transdisciplinary research in many of the more than one hundred transdisciplinary scientific research papers reviewed. This research work now will undertake the challenge of applying a System of Systems (SoS) [205] approach to develop a new transdisciplinary framework which also includes the engineering disciplines for the solution of global complex problems.

The primary intent of this research was to understand and assess the importance of transdisciplinary research and education through survey. To the best knowledge of the author of this dissertation, no previous or similar surveys have been conducted by other researchers on this topic. In particular, having the view of different groups of people from research institutes, business, industry and academia on transdisciplinary activities

has been a rich source of information that will help the researchers and educators better understand key problems of transdisciplinary activities.

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APPENDIX A

Survey Results for Transdisciplinary Research Objectives (Group: Researchers)

Table 6.1-A Survey result for three treatments A, B, and C (Question #1)

# of Sample	A	B	C
1	4	5	3
2	4	5	4
3	4	3	5
4	3	3	4
5	1	5	3
6	5	4	5
7	4	4	3
8	4	4	4
9	5	2	3
10	4	3	5
11	3	4	3
12	5	4	4
13	4	5	3
14	5	4	5
15	4	4	4
16	4	4	3
17	5	4	4
18	5	3	5
19	5	4	4
20	3	3	3
21	5	4	5
22	4	3	5
23	3	4	5
24	5	3	5
25	5	4	3
26	4	3	5
27	4	3	5
28	2	4	3
<i>SUM</i>	<i>113</i>	<i>105</i>	<i>113</i>
<i>SQUARE</i>	<i>483</i>	<i>409</i>	<i>477</i>
<i>MEAN</i>	<i>4.04</i>	<i>3.75</i>	<i>4.04</i>
<i>SD</i>	<i>1.00</i>	<i>0.75</i>	<i>0.88</i>
<i>SD ERROR</i>	<i>0.19</i>	<i>0.14</i>	<i>0.17</i>

Table 6.2-A Survey result for three treatments A, B, and C (Question #2)

# of Sample	A	B	C
1	4	5	3
2	4	4	4
3	4	5	3
4	3	3	4
5	1	5	3
6	5	4	5
7	4	5	3
8	5	4	5
9	5	2	4
10	4	3	5
11	4	3	4
12	4	3	3
13	3	5	4
14	5	4	5
15	4	4	4
16	2	2	2
17	5	5	5
18	5	3	5
19	3	2	2
20	5	5	4
21	4	5	3
22	4	3	5
23	3	3	3
24	5	3	5
25	5	4	3
26	4	3	5
27	5	4	3
28	4	2	4
<i>SUM</i>	<i>113</i>	<i>103</i>	<i>108</i>
<i>SQUARE</i>	<i>483</i>	<i>409</i>	<i>442</i>
<i>MEAN</i>	<i>4.04</i>	<i>3.68</i>	<i>3.86</i>
<i>SD</i>	<i>1.00</i>	<i>1.06</i>	<i>0.97</i>
<i>SD ERROR</i>	<i>0.19</i>	<i>0.20</i>	<i>0.18</i>

Table 6.3-A Survey result for three treatments A, B, and C (Question #3)

# of Sample	A	B	C
1	5	4	3
2	5	5	4
3	5	3	4
4	4	4	3
5	3	1	5
6	5	4	5
7	5	4	5
8	5	4	5
9	5	2	4
10	4	3	5
11	4	5	3
12	3	3	3
13	5	2	2
14	5	3	5
15	4	4	4
16	5	5	4
17	4	5	4
18	5	5	4
19	5	5	5
20	5	5	4
21	5	3	5
22	3	4	5
23	3	3	5
24	5	4	5
25	5	3	4
26	4	3	5
27	4	5	3
28	3	5	4
<i>SUM</i>	<i>123</i>	<i>106</i>	<i>117</i>
<i>SQUARE</i>	<i>557</i>	<i>434</i>	<i>509</i>
<i>MEAN</i>	<i>4.39</i>	<i>3.79</i>	<i>4.18</i>
<i>SD</i>	<i>0.79</i>	<i>1.10</i>	<i>0.86</i>
<i>SD ERROR</i>	<i>0.15</i>	<i>0.21</i>	<i>0.16</i>

Table 6.4-A Survey result for three treatments A, B, and C (Question #4)

# of Sample	A	B	C
1	4	3	5
2	5	5	4
3	5	5	3
4	4	4	4
5	5	1	3
6	5	4	5
7	5	5	4
8	5	4	5
9	5	3	4
10	4	3	5
11	4	4	4
12	5	3	4
13	4	3	5
14	5	3	5
15	4	4	4
16	5	5	4
17	5	4	5
18	5	4	5
19	5	5	4
20	5	5	5
21	5	3	4
22	3	4	5
23	5	5	5
24	5	3	5
25	5	3	5
26	4	3	5
27	4	5	3
28	4	5	3
<i>SUM</i>	<i>129</i>	<i>108</i>	<i>122</i>
<i>SQUARE</i>	<i>603</i>	<i>444</i>	<i>546</i>
<i>MEAN</i>	<i>4.61</i>	<i>3.86</i>	<i>4.36</i>
<i>SD</i>	<i>0.57</i>	<i>1.01</i>	<i>0.73</i>
<i>SD ERROR</i>	<i>0.11</i>	<i>0.19</i>	<i>0.14</i>

Table 6.5-A Survey result for four treatments A, B, C, and D (Question #5)

# of Sample	A	B	C	D
1	5	4	2	3
2	4	3	5	3
3	5	2	4	3
4	4	4	4	4
5	3	3	5	5
6	4	5	4	3
7	4	5	5	5
8	4	5	5	3
9	5	3	5	5
10	2	4	3	5
11	3	5	3	4
12	4	4	4	2
13	4	4	4	5
14	5	4	5	4
15	4	4	4	4
16	4	4	5	3
17	4	5	5	4
18	4	5	5	3
19	4	5	4	4
20	4	4	5	5
21	2	5	5	3
22	5	3	4	2
23	2	3	5	3
24	5	2	4	3
25	4	4	5	2
26	3	5	4	4
27	3	4	5	2
28	3	4	4	2
<i>SUM</i>	<i>107</i>	<i>112</i>	<i>122</i>	<i>98</i>
<i>SQUARE</i>	<i>431</i>	<i>470</i>	<i>548</i>	<i>372</i>
<i>MEAN</i>	<i>3.82</i>	<i>4.00</i>	<i>4.36</i>	<i>3.50</i>
<i>SD</i>	<i>0.90</i>	<i>0.90</i>	<i>0.78</i>	<i>1.04</i>
<i>SD ERROR</i>	<i>0.17</i>	<i>0.17</i>	<i>0.15</i>	<i>0.20</i>

Table 6.6-A Survey result for four treatments A, B, C, and D (Question #6)

# of Sample	A	B	C	D
1	2	5	4	3
2	3	4	5	5
3	2	3	5	4
4	3	4	4	3
5	3	3	5	5
6	5	3	3	4
7	4	5	4	5
8	5	3	4	5
9	4	4	5	4
10	4	5	2	3
11	3	3	4	5
12	3	3	3	3
13	2	5	5	4
14	5	4	4	5
15	5	5	5	5
16	4	3	5	5
17	5	4	5	5
18	4	3	5	5
19	3	2	2	4
20	4	2	3	5
21	4	3	2	5
22	3	2	4	5
23	4	2	2	5
24	2	3	5	4
25	3	2	4	5
26	5	4	3	4
27	3	2	5	4
28	4	2	3	4
<i>SUM</i>	<i>101</i>	<i>93</i>	<i>110</i>	<i>123</i>
<i>SQUARE</i>	<i>391</i>	<i>339</i>	<i>464</i>	<i>555</i>
<i>MEAN</i>	<i>3.61</i>	<i>3.32</i>	<i>3.93</i>	<i>4.39</i>
<i>SD</i>	<i>0.99</i>	<i>1.06</i>	<i>1.09</i>	<i>0.74</i>
<i>SD ERROR</i>	0.19	0.20	0.21	0.14

Table 6.7-A Survey result for four treatments A, B, C, and D (Question #7)

# of Sample	A	B	C	D
1	4	2	3	5
2	4	4	4	4
3	3	4	5	2
4	3	4	3	4
5	1	3	5	1
6	4	4	4	5
7	4	5	5	3
8	5	3	4	4
9	2	5	3	4
10	3	2	3	2
11	3	3	3	3
12	3	1	4	5
13	4	5	5	4
14	4	4	4	4
15	5	4	5	3
16	5	4	5	4
17	5	5	5	3
18	3	4	5	4
19	4	5	4	3
20	5	3	4	4
21	4	3	5	2
22	3	1	5	1
23	5	2	4	3
24	5	2	5	1
25	3	5	4	4
26	2	3	5	4
27	3	3	4	2
<i>SUM</i>	<i>99</i>	<i>93</i>	<i>115</i>	<i>88</i>
<i>SQUARE</i>	<i>393</i>	<i>359</i>	<i>505</i>	<i>324</i>
<i>MEAN</i>	<i>3.67</i>	<i>3.44</i>	<i>4.26</i>	<i>3.26</i>
<i>SD</i>	<i>1.07</i>	<i>1.22</i>	<i>0.76</i>	<i>1.20</i>
<i>SD ERROR</i>	<i>0.21</i>	<i>0.23</i>	<i>0.15</i>	<i>0.23</i>

Table 6.8-A Survey result for four treatments A, B, C, and D (Question #8)

# of Sample	A	B	C	D
1	4	2	3	5
2	5	5	5	5
3	4	2	3	5
4	4	4	4	4
5	2	5	5	5
6	4	5	4	3
7	4	5	5	4
8	4	5	5	3
9	4	5	4	5
10	2	4	3	5
11	4	5	3	5
12	4	3	4	2
13	4	4	5	5
14	5	5	5	4
15	4	4	4	4
16	5	5	5	4
17	5	4	5	3
18	4	5	5	5
19	3	4	5	5
20	2	4	5	3
21	4	3	5	1
22	4	4	5	2
23	2	4	3	3
24	3	5	5	4
25	5	2	4	3
26	3	3	4	2
<i>SUM</i>	<i>98</i>	<i>106</i>	<i>113</i>	<i>99</i>
<i>SQUARE</i>	<i>392</i>	<i>458</i>	<i>507</i>	<i>413</i>
<i>MEAN</i>	<i>3.77</i>	<i>4.08</i>	<i>4.35</i>	<i>3.81</i>
<i>SD</i>	<i>0.95</i>	<i>1.02</i>	<i>0.80</i>	<i>1.20</i>
<i>SD ERROR</i>	<i>0.19</i>	<i>0.20</i>	<i>0.16</i>	<i>0.24</i>

Table 6.9-A Survey result for four treatments A, B, C, and D (Question #9)

# of Sample	A	B	C	D
1	4	2	3	5
2	5	5	5	5
3	4	3	5	2
4	4	3	4	4
5	3	1	5	1
6	4	5	4	3
7	4	4	5	4
8	3	5	5	4
9	5	3	3	4
10	2	4	3	5
11	2	3	4	2
12	3	2	3	2
13	4	2	5	3
14	5	5	5	4
15	4	4	4	4
16	4	4	5	3
17	5	5	5	3
18	4	3	4	3
19	4	5	5	5
20	3	4	5	2
21	4	3	5	2
22	4	3	5	1
23	2	2	4	2
24	3	5	5	4
25	5	2	4	3
26	4	3	2	3
<i>SUM</i>	<i>98</i>	<i>90</i>	<i>112</i>	<i>83</i>
<i>SQUARE</i>	<i>390</i>	<i>348</i>	<i>502</i>	<i>301</i>
<i>MEAN</i>	<i>3.77</i>	<i>3.46</i>	<i>4.31</i>	<i>3.19</i>
<i>SD</i>	<i>0.91</i>	<i>1.21</i>	<i>0.88</i>	<i>1.20</i>
<i>SD ERROR</i>	<i>0.18</i>	<i>0.24</i>	<i>0.17</i>	<i>0.24</i>

Table 6.10-A Survey result for four treatments A, B, C, and D (Question #10)

# of Sample	A	B	C	D
1	5	2	4	3
2	3	3	3	3
3	5	3	4	2
4	3	3	3	3
5	1	1	5	1
6	4	5	4	3
7	5	4	4	4
8	4	5	5	4
9	4	4	5	4
10	2	4	3	5
11	3	3	3	2
12	2	2	2	2
13	1	2	5	1
14	5	4	5	5
15	4	4	4	4
16	3	4	4	3
17	4	5	4	4
18	3	3	4	2
19	5	5	4	2
20	4	3	5	1
21	3	4	5	2
22	3	1	4	1
23	3	4	4	2
24	3	5	5	4
25	2	3	5	4
26	3	4	2	4
<i>SUM</i>	<i>87</i>	<i>90</i>	<i>105</i>	<i>75</i>
<i>SQUARE</i>	<i>325</i>	<i>346</i>	<i>445</i>	<i>255</i>
<i>MEAN</i>	<i>3.35</i>	<i>3.46</i>	<i>4.04</i>	<i>2.88</i>
<i>SD</i>	<i>1.16</i>	<i>1.17</i>	<i>0.92</i>	<i>1.24</i>
<i>SD ERROR</i>	<i>0.23</i>	<i>0.23</i>	<i>0.18</i>	<i>0.24</i>

Survey Results for Comparison of Interdisciplinary and Transdisciplinary Research
(Group: Researchers)

Table 6.11-A Survey result for two treatments A and B (Question #11)

# 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
<i>SUM</i>	<i>102</i>	<i>115</i>
<i>SQUARE</i>	<i>414</i>	<i>525</i>
<i>MEAN</i>	<i>3.92</i>	<i>4.42</i>
<i>SD</i>	<i>0.74</i>	<i>0.81</i>
<i>SD ERROR</i>	<i>0.15</i>	<i>0.16</i>

Table 6.12-A Survey result for two treatments A and B (Question #12)

# 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
<i>SUM</i>	<i>106</i>	<i>115</i>
<i>SQUARE</i>	<i>448</i>	<i>525</i>
<i>MEAN</i>	<i>4.08</i>	<i>4.42</i>
<i>SD</i>	<i>0.80</i>	<i>0.81</i>
<i>SD ERROR</i>	<i>0.16</i>	<i>0.16</i>

Table 6.13-A Survey result for two treatments A and B (Question #13)

# 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
<i>SUM</i>	<i>101</i>	<i>114</i>
<i>SQUARE</i>	<i>407</i>	<i>514</i>
<i>MEAN</i>	<i>3.88</i>	<i>4.38</i>
<i>SD</i>	<i>0.77</i>	<i>0.75</i>
<i>SD ERROR</i>	<i>0.15</i>	<i>0.15</i>

Survey Results for Transdisciplinary Research Objectives (Group: Academics)

Table 6.14-A Survey result for three treatments A, B, and C (Question #1)

# of Sample	A	B	C
1	4	5	4
2	2	3	4
3	3	4	5
4	5	3	4
5	3	5	3
6	3	1	5
7	2	2	4
8	5	4	5
9	4	3	5
10	3	5	4
11	3	3	3
12	4	2	5
13	3	5	2
14	5	4	3
15	4	3	5
16	3	5	1
17	5	5	5
18	5	5	4
19	4	3	4
20	3	3	3
21	4	4	4
22	4	3	5
23	4	5	3
24	5	5	5
25	5	5	5
26	5	5	5
27	5	5	5
28	5	5	5
29	4	4	5
30	5	5	5
31	5	3	4
32	4	5	5
33	4	3	5
34	5	5	4
35	4	3	3
36	3	4	4
<i>SUM</i>	<i>144</i>	<i>142</i>	<i>150</i>
<i>SQUARE</i>	<i>606</i>	<i>604</i>	<i>660</i>
<i>MEAN</i>	<i>4.00</i>	<i>3.94</i>	<i>4.17</i>
<i>SD</i>	<i>0.93</i>	<i>1.12</i>	<i>1.00</i>
<i>SD ERROR</i>	<i>0.15</i>	<i>0.19</i>	<i>0.17</i>

Table 6.15-A Survey result for three treatments A, B, and C (Question #2)

# of Sample	A	B	C
1	5	5	4
2	2	3	4
3	4	3	5
4	4	5	4
5	4	5	3
6	1	3	5
7	2	2	4
8	4	3	5
9	5	2	3
10	3	5	4
11	3	3	3
12	5	3	4
13	4	5	3
14	5	4	3
15	5	4	4
16	4	5	3
17	5	5	5
18	5	5	4
19	3	3	3
20	5	4	5
21	2	2	2
22	4	3	5
23	4	4	4
24	5	5	5
25	4	3	4
26	5	5	5
27	5	5	5
28	5	5	5
29	4	5	5
30	5	5	5
31	3	4	5
32	4	5	5
33	5	4	4
34	5	5	4
35	4	3	3
36	4	5	4
<i>SUM</i>	<i>146</i>	<i>145</i>	<i>148</i>
<i>SQUARE</i>	<i>632</i>	<i>623</i>	<i>634</i>
<i>MEAN</i>	<i>4.06</i>	<i>4.03</i>	<i>4.11</i>
<i>SD</i>	<i>1.07</i>	<i>1.06</i>	<i>0.85</i>
<i>SD ERROR</i>	<i>0.18</i>	<i>0.18</i>	<i>0.14</i>

Table 6.16-A Survey result for three treatments A, B, and C (Question #3)

# of Sample	A	B	C
1	4	4	5
2	3	4	2
3	5	4	4
4	3	5	3
5	4	5	3
6	5	1	3
7	2	2	4
8	5	4	4
9	5	3	4
10	4	5	4
11	5	3	5
12	5	4	3
13	4	3	5
14	4	5	3
15	4	5	3
16	2	5	4
17	5	5	5
18	5	5	4
19	4	3	4
20	3	3	3
21	2	2	2
22	4	3	5
23	4	4	4
24	5	5	5
25	5	5	5

26	5	4	5
27	5	5	5
28	5	5	5
29	4	4	5
30	5	5	5
31	5	3	4
32	4	5	5
33	4	5	4
34	5	5	4
35	4	3	3
36	4	5	4
<i>SUM</i>	<i>151</i>	<i>146</i>	<i>145</i>
<i>SQUARE</i>	<i>663</i>	<i>634</i>	<i>613</i>
<i>MEAN</i>	<i>4.19</i>	<i>4.06</i>	<i>4.03</i>
<i>SD</i>	<i>0.92</i>	<i>1.09</i>	<i>0.91</i>
<i>SD ERROR</i>	<i>0.15</i>	<i>0.18</i>	<i>0.15</i>

Table 6.17-A Survey result for three treatments A, B, and C (Question #4)

# of Sample	A	B	C
1	5	5	5
2	4	5	3
3	5	4	3
4	5	5	3
5	4	5	3
6	1	3	5
7	4	4	2
8	5	5	5
9	5	3	4
10	4	5	4
11	5	3	5
12	4	3	5
13	5	4	4
14	5	3	4
15	4	5	3
16	5	4	2
17	5	5	5
18	5	5	4
19	4	3	4
20	3	3	3
21	4	4	4
22	3	4	5
23	4	4	4
24	5	5	5
25	5	4	4

26	5	5	5
27	5	5	5
28	5	5	5
29	5	4	5
30	5	5	5
31	5	4	4
32	4	5	5
33	5	4	4
34	5	5	5
35	4	3	3
36	4	3	4
<i>SUM</i>	<i>160</i>	<i>151</i>	<i>148</i>
<i>SQUARE</i>	<i>736</i>	<i>657</i>	<i>638</i>
<i>MEAN</i>	<i>4.44</i>	<i>4.19</i>	<i>4.11</i>
<i>SD</i>	<i>0.84</i>	<i>0.82</i>	<i>0.92</i>
<i>SD ERROR</i>	<i>0.14</i>	<i>0.14</i>	<i>0.15</i>

Table 6.18-A Survey result for four treatments A, B, C, and D (Question #5)

# of Sample	A	B	C	D
1	4	5	4	4
2	2	5	3	4
3	3	4	5	4
4	4	5	2	4
5	3	5	4	5
6	1	5	2	4
7	2	5	2	5
8	4	2	3	5
9	2	4	3	3
10	3	3	3	3
11	3	4	2	5
12	4	2	5	4
13	4	5	5	3
14	5	5	5	5
15	3	4	5	3
16	5	5	5	5
17	5	5	4	4
18	5	4	4	3
19	4	4	5	5
20	4	3	3	3
21	4	5	2	3
22	3	4	5	3
23	3	5	4	4
24	5	5	5	5
25	5	4	5	3
26	5	4	4	3
27	4	5	4	4
28	3	5	5	4
29	5	5	5	5
30	2	4	3	3
31	3	3	5	4
32	4	3	4	3
33	4	4	5	5
34	4	3	4	3
<i>SUM</i>	<i>124</i>	<i>143</i>	<i>134</i>	<i>133</i>
<i>SQUARE</i>	<i>490</i>	<i>629</i>	<i>568</i>	<i>543</i>
<i>MEAN</i>	<i>3.65</i>	<i>4.21</i>	<i>3.94</i>	<i>3.91</i>
<i>SD</i>	<i>1.07</i>	<i>0.91</i>	<i>1.1</i>	<i>0.83</i>
<i>SD ERROR</i>	<i>0.18</i>	<i>0.16</i>	<i>0.19</i>	<i>0.14</i>

Table 6.19-A Survey result for four treatments A, B, C, and D (Question #6)

# of Sample	A	B	C	D
1	4	5	4	4
2	5	3	4	2
3	3	3	5	4
4	5	5	4	3
5	4	5	3	4
6	1	2	4	5
7	5	5	2	2
8	3	4	5	2
9	3	5	3	4
10	3	3	3	3
11	2	3	5	4
12	2	4	4	5
13	5	3	4	5
14	3	3	4	5
15	2	3	4	5
16	5	5	5	5
17	5	4	5	4
18	5	3	5	4
19	4	5	4	5
20	4	4	4	4
21	3	4	5	2
22	5	4	3	5
23	5	4	3	4
24	5	4	5	4
25	4	3	5	5
26	4	3	5	5
27	5	4	4	4
28	5	3	4	5
29	5	5	5	5
30	4	2	3	4
31	3	4	3	5
32	3	4	4	4
33	5	4	5	5
34	3	3	4	4
<i>SUM</i>	<i>132</i>	<i>128</i>	<i>139</i>	<i>140</i>
<i>SQUARE</i>	<i>556</i>	<i>508</i>	<i>591</i>	<i>608</i>
<i>MEAN</i>	<i>3.88</i>	<i>3.76</i>	<i>4.09</i>	<i>4.12</i>
<i>SD</i>	<i>1.15</i>	<i>0.89</i>	<i>0.83</i>	<i>0.98</i>
<i>SD ERROR</i>	<i>0.20</i>	<i>0.15</i>	<i>0.14</i>	<i>0.17</i>

Table 6.20-A Survey result for four treatments A, B, C, and D (Question #7)

# of Sample	A	B	C	D
1	4	4	5	4
2	4	5	2	3
3	5	3	4	4
4	5	3	4	3
5	3	4	4	5
6	5	2	4	1
7	2	5	2	5
8	5	2	3	4
9	4	4	5	5
10	3	3	3	3
11	5	2	4	3
12	4	3	4	3
13	5	5	5	4
14	4	3	5	3
15	2	1	5	4
16	5	5	5	5
17	5	5	4	4
18	5	5	4	3
19	5	4	5	4
20	4	4	4	4
21	2	4	3	5
22	3	4	5	3
23	5	4	5	4
24	4	5	4	4
25	5	4	5	3

26	5	4	5	3
27	4	5	4	4
28	5	5	5	4
29	5	5	5	5
30	4	3	5	1
31	3	3	5	4
32	4	3	5	2
33	5	5	5	4
34	4	3	4	3
<i>SUM</i>	<i>142</i>	<i>129</i>	<i>146</i>	<i>123</i>
<i>SQUARE</i>	<i>624</i>	<i>529</i>	<i>652</i>	<i>479</i>
<i>MEAN</i>	<i>4.18</i>	<i>3.79</i>	<i>4.29</i>	<i>3.62</i>
<i>SD</i>	<i>0.97</i>	<i>1.09</i>	<i>0.87</i>	<i>1.02</i>
<i>SD ERROR</i>	<i>0.17</i>	<i>0.19</i>	<i>0.15</i>	<i>0.17</i>

Table 6.21-A Survey result for four treatments A, B, C, and D (Question #8)

# of Sample	A	B	C	D
1	4	5	5	4
2	3	5	2	4
3	3	4	3	5
4	2	4	2	5
5	3	4	4	5
6	5	2	4	1
7	2	5	2	5
8	2	3	5	4
9	3	4	3	5
10	4	3	2	5
11	4	4	4	4
12	3	4	5	3
13	4	3	5	3
14	3	2	5	4
15	5	5	5	5
16	5	5	4	4
17	5	4	4	3
18	3	4	3	4
19	3	3	3	3
20	3	5	2	4
21	3	4	5	3
22	5	4	5	4
23	5	5	5	5
24	5	4	5	3
25	5	3	5	3

26	4	5	4	4
27	4	5	5	3
28	5	5	5	5
29	2	4	3	2
30	3	4	5	3
31	5	3	4	4
32	5	5	5	4
33	4	3	4	3
<i>SUM</i>	<i>124</i>	<i>132</i>	<i>132</i>	<i>126</i>
<i>SQUARE</i>	<i>502</i>	<i>554</i>	<i>568</i>	<i>512</i>
<i>MEAN</i>	<i>3.76</i>	<i>4.00</i>	<i>4.00</i>	<i>3.82</i>
<i>SD</i>	<i>1.06</i>	<i>0.90</i>	<i>1.12</i>	<i>0.98</i>
<i>SD ERROR</i>	<i>0.18</i>	<i>0.16</i>	<i>0.19</i>	<i>0.17</i>

Table 6.22-A Survey result for four treatments A, B, C, and D (Question #9)

# of Sample	A	B	C	D
1	4	5	5	4
2	3	5	4	2
3	5	3	4	2
4	3	4	2	5
5	3	4	4	5
6	2	5	1	4
7	2	5	2	5
8	5	2	3	4
9	4	4	5	5
10	5	3	2	4
11	4	4	4	4
12	3	4	5	2
13	5	5	5	5
14	4	2	5	3
15	5	5	5	5
16	5	5	4	4
17	4	5	5	3
18	5	4	5	5
19	2	2	2	2
20	2	4	3	5
21	3	4	5	3
22	4	4	4	3
23	4	5	4	5
24	5	4	5	3
25	5	4	5	3

26	4	5	4	4
27	4	5	5	4
28	5	5	5	5
29	4	3	3	2
30	3	3	4	3
31	4	2	5	3
32	5	5	5	4
33	4	3	4	3
<i>SUM</i>	<i>129</i>	<i>132</i>	<i>133</i>	<i>123</i>
<i>SQUARE</i>	<i>537</i>	<i>562</i>	<i>579</i>	<i>495</i>
<i>MEAN</i>	<i>3.91</i>	<i>4.00</i>	<i>4.03</i>	<i>3.73</i>
<i>SD</i>	<i>1.01</i>	<i>1.03</i>	<i>1.16</i>	<i>1.07</i>
<i>SD ERROR</i>	<i>0.18</i>	<i>0.18</i>	<i>0.20</i>	<i>0.19</i>

Table 6.23-A Survey result for four treatments A, B, C, and D (Question #10)

# of Sample	A	B	C	D
1	4	4	5	4
2	4	3	5	2
3	4	3	5	2
4	4	4	4	3
5	3	4	4	5
6	5	2	4	1
7	2	5	2	5
8	4	2	3	5
9	3	4	4	5
10	5	3	2	4
11	4	4	4	4
12	3	4	5	2
13	4	3	5	3
14	2	3	5	4
15	5	5	5	5
16	5	5	4	4
17	4	4	4	3
18	2	4	2	4
19	2	2	2	2
20	4	3	5	2
21	3	4	5	3
22	5	4	5	3
23	5	5	5	5
24	5	4	5	3
25	5	4	5	3

26	4	5	4	4
27	5	5	5	4
28	5	5	5	5
29	3	1	2	1
30	3	3	4	3
31	5	2	4	4
32	5	4	5	4
33	4	3	4	3
<i>SUM</i>	<i>130</i>	<i>120</i>	<i>137</i>	<i>114</i>
<i>SQUARE</i>	<i>546</i>	<i>472</i>	<i>605</i>	<i>438</i>
<i>MEAN</i>	<i>3.94</i>	<i>3.64</i>	<i>4.15</i>	<i>3.45</i>
<i>SD</i>	<i>1.03</i>	<i>1.06</i>	<i>1.06</i>	<i>1.18</i>
<i>SD ERROR</i>	<i>0.18</i>	<i>0.18</i>	<i>0.19</i>	<i>0.2</i>

Table 6.24-A Survey result for two treatments A and B (Question #11)

# of Sample	A	B
1	5	5
2	4	3
3	3	5
4	4	4
5	4	4
6	3	5
7	5	5
8	4	5
9	5	4
10	2	2
11	5	5
12	5	5
13	4	5
14	2	4
15	5	5
16	5	5
17	5	5
18	4	5
19	3	3
20	4	5
21	3	4
22	4	5
23	2	5
24	5	4
25	4	5

26	5	5
27	4	5
28	4	4
29	5	4
30	3	5
31	4	5
32	5	5
33	3	4
<i>SUM</i>	<i>132</i>	<i>149</i>
<i>SQUARE</i>	<i>558</i>	<i>691</i>
<i>MEAN</i>	<i>4.00</i>	<i>4.52</i>
<i>SD</i>	<i>0.97</i>	<i>0.76</i>
<i>SD ERROR</i>	<i>0.17</i>	<i>0.13</i>

Table 6.25-A Survey result for two treatments A and B (Question #12)

# of Sample	A	B
1	4	5
2	3	4
3	4	5
4	3	4
5	5	5
6	3	5
7	2	2
8	4	5
9	4	5
10	5	5
11	3	3
12	5	4
13	5	4
14	4	3
15	5	5
16	4	4
17	5	5
18	3	5
19	2	2
20	4	5
21	3	4
22	3	5
23	3	5
24	3	5
25	3	5

26	4	5
27	3	5
28	4	4
29	4	5
30	4	5
31	4	5
32	5	5
33	3	4
<i>SUM</i>	<i>123</i>	<i>147</i>
<i>SQUARE</i>	<i>483</i>	<i>679</i>
<i>MEAN</i>	<i>3.73</i>	<i>4.45</i>
<i>SD</i>	<i>0.88</i>	<i>0.87</i>
<i>SD ERROR</i>	<i>0.15</i>	<i>0.15</i>

Table 6.26-A Survey result for two treatments A and B (Question #13)

# of Sample	A	B
1	4	5
2	4	5
3	4	5
4	5	5
5	4	4
6	3	5
7	2	5
8	5	4
9	4	5
10	4	5
11	4	4
12	3	3
13	4	5
14	1	5
15	5	5
16	5	4
17	5	5
18	4	4
19	4	4
20	4	5
21	3	4
22	2	5
23	3	5
24	2	5
25	4	5

26	4	5
27	4	5
28	4	4
29	4	5
30	3	5
31	4	5
32	5	5
33	3	3
<i>SUM</i>	<i>123</i>	<i>153</i>
<i>SQUARE</i>	<i>489</i>	<i>721</i>
<i>MEAN</i>	<i>3.73</i>	<i>4.64</i>
<i>SD</i>	<i>0.98</i>	<i>0.60</i>
<i>SD ERROR</i>	<i>0.17</i>	<i>0.10</i>

Survey Results for Transdisciplinary Research Objectives (Group: Industry)

Table 6.27-A Survey result for three treatments A, B, and C (Question #1)

# of Sample	A	B	C
1	5	4	4
2	4	2	5
3	5	3	4
4	3	4	2
5	5	4	2
6	4	4	3
7	4	4	4
8	5	4	3
9	3	5	1
10	3	4	5
11	3	5	4
12	4	3	5
13	4	4	3
14	5	5	4
15	4	3	5
16	5	3	4
17	5	1	3
18	5	3	4
19	4	3	5
20	4	4	5
21	5	3	4
22	4	4	4
23	3	3	3
24	5	3	4
25	4	4	5
26	3	1	5
27	4	4	5
28	5	4	4
29	5	4	3
30	5	3	3
31	3	4	5
32	4	2	5

33	5	4	3
34	4	1	5
35	5	3	4
36	4	5	4
37	4	3	4
38	4	3	5
39	3	5	4
40	5	4	5
41	5	2	4
42	5	4	5
43	4	5	3
44	4	4	3
45	5	5	5
SUM	191	159	179
SQUARE	835	611	755
MEAN	4.24	3.53	3.98
SD	0.74	1.06	0.99
SD ERROR	0.11	0.16	0.15

Table 6.28-A Survey result for three treatments A, B, and C (Question #2)

# of Sample	A	B	C
1	4	4	3
2	3	5	4
3	4	3	5
4	2	4	3
5	3	4	5
6	5	3	5
7	4	4	4
8	4	3	5
9	3	5	1
10	5	3	4
11	3	5	4
12	3	4	5
13	5	4	4
14	5	5	4
15	4	3	5
16	5	3	4
17	5	1	3
18	5	3	4
19	4	3	5
20	4	4	5
21	5	3	4
22	4	4	4
23	4	4	4
24	5	3	4
25	4	4	5
26	5	1	3
27	5	3	4
28	5	4	5
29	4	5	3
30	5	4	3
31	3	5	4
32	5	3	3
33	5	3	4
34	4	3	5
35	4	5	3
36	4	5	5
37	4	5	3
38	4	3	5
39	4	3	5
40	5	4	5
41	5	1	3
42	4	5	5
43	3	3	3
44	4	3	4
45	3	3	3
<i>SUM</i>	<i>187</i>	<i>162</i>	<i>181</i>
<i>SQUARE</i>	<i>805</i>	<i>632</i>	<i>765</i>
<i>MEAN</i>	<i>4.16</i>	<i>3.6</i>	<i>4.02</i>
<i>SD</i>	<i>0.80</i>	<i>1.05</i>	<i>0.92</i>
<i>SD ERROR</i>	<i>0.12</i>	<i>0.16</i>	<i>0.14</i>

Table 6.29-A Survey result for three treatments A, B, and C (Question #3)

# of Sample	A	B	C
1	4	3	3
2	5	2	4
3	5	5	4
4	2	4	3
5	4	4	5
6	5	5	4
7	4	4	4
8	4	5	3
9	3	5	1
10	4	3	5
11	3	5	4
12	4	3	5
13	4	5	3
14	4	5	4
15	5	3	4
16	5	3	4
17	5	1	3
18	4	5	3
19	4	5	3
20	4	5	5
21	5	4	3
22	3	3	3
23	4	4	5
24	5	3	4
25	3	3	3
26	5	1	3
27	4	3	5
28	5	5	5
29	3	4	5
30	4	3	5
31	5	4	3
32	3	4	4
33	5	3	4
34	4	3	5
35	5	4	3
36	3	3	3
37	3	4	5
38	4	3	5
39	3	5	4
40	5	5	4
41	5	2	4
42	4	4	4
43	3	3	2
44	3	2	3
45	4	4	4
<i>SUM</i>	<i>182</i>	<i>166</i>	<i>172</i>
<i>SQUARE</i>	<i>766</i>	<i>666</i>	<i>696</i>
<i>MEAN</i>	<i>4.04</i>	<i>3.69</i>	<i>3.82</i>
<i>SD</i>	<i>0.82</i>	<i>1.1</i>	<i>0.94</i>
<i>SD ERROR</i>	<i>0.12</i>	<i>0.16</i>	<i>0.14</i>

Table 6.30-A Survey result for three treatments A, B, and C (Question #4)

# of Sample	A	B	C
1	4	4	4
2	5	4	3
3	5	4	4
4	5	3	4
5	5	3	4
6	5	5	5
7	4	4	4
8	3	4	5
9	3	5	1
10	5	3	4
11	1	3	2
12	5	3	4
13	4	4	4
14	5	5	4
15	5	4	3
16	4	3	5
17	5	1	3
18	4	5	3
19	5	2	3
20	5	5	4
21	5	3	4
22	4	4	5
23	4	4	4
24	5	4	3
25	3	3	3
26	5	1	3
27	5	4	3
28	5	5	5
29	4	3	5
30	4	5	3
31	3	4	5
32	4	5	4

33	5	4	3
34	4	5	3
35	5	4	3
36	4	4	4
37	3	5	4
38	4	3	5
39	3	4	5
40	4	5	4
41	5	3	4
42	5	3	3
43	4	3	3
44	5	3	3
45	3	3	3
<i>SUM</i>	<i>192</i>	<i>168</i>	<i>167</i>
<i>SQUARE</i>	<i>854</i>	<i>672</i>	<i>655</i>
<i>MEAN</i>	<i>4.27</i>	<i>3.73</i>	<i>3.71</i>
<i>SD</i>	<i>0.89</i>	<i>1.01</i>	<i>0.89</i>
<i>SD ERROR</i>	<i>0.13</i>	<i>0.15</i>	<i>0.13</i>

Table 6.31-A Survey result for four treatments A, B, C, and D (Question #5)

# of Sample	A	B	C	D
1	4	5	3	2
2	2	3	4	1
3	2	3	4	5
4	5	3	4	2
5	4	4	4	3
6	4	4	4	4
7	3	4	2	1
8	4	4	3	5
9	2	5	4	3
10	2	5	3	4
11	3	4	5	5
12	4	4	4	3
13	4	4	5	5
14	3	5	2	4
15	4	3	5	2
16	5	4	1	3
17	3	5	4	2
18	5	3	4	3
19	5	5	5	3
20	2	4	5	3
21	4	4	5	5
22	3	4	4	4
23	3	4	5	2
24	4	3	4	3
25	1	3	5	2
26	2	4	5	3
27	4	5	4	3
28	2	4	5	3
29	4	2	5	3
30	3	2	4	5
31	3	4	3	1
32	2	4	3	5
33	3	5	4	2
34	3	5	2	4
35	4	4	4	5
36	2	3	4	5
37	4	2	5	2
38	1	5	2	4
39	4	5	4	5
40	4	3	1	5
41	4	4	5	4
42	5	4	5	3
43	4	4	4	4
<i>SUM</i>	<i>143</i>	<i>168</i>	<i>167</i>	<i>145</i>
<i>SQUARE</i>	<i>525</i>	<i>688</i>	<i>701</i>	<i>555</i>
<i>MEAN</i>	<i>3.33</i>	<i>3.91</i>	<i>3.88</i>	<i>3.37</i>
<i>SD</i>	<i>1.08</i>	<i>0.87</i>	<i>1.12</i>	<i>1.25</i>
<i>SD ERROR</i>	<i>0.17</i>	<i>0.13</i>	<i>0.17</i>	<i>0.19</i>

Table 6.32-A Survey result for four treatments A, B, C, and D (Question #6)

# of Sample	A	B	C	D
1	4	2	4	3
2	3	1	2	4
3	4	3	2	5
4	5	4	3	4
5	5	4	4	5
6	4	4	4	4
7	3	2	5	4
8	3	5	3	4
9	5	4	2	3
10	4	3	2	1
11	4	2	3	5
12	4	3	4	5
13	4	5	4	4
14	3	2	4	5
15	5	2	4	3
16	4	3	5	1
17	3	2	5	4
18	4	3	2	4
19	5	3	5	5
20	4	3	2	5
21	4	5	4	5
22	4	4	4	4
23	4	2	3	5
24	3	3	4	4
25	1	2	4	5
26	5	3	2	4
27	5	4	5	4
28	4	3	2	5
29	4	3	2	5
30	3	4	2	5
31	4	1	3	4
32	4	5	3	2

33	3	2	4	5
34	2	3	4	5
35	4	5	4	4
36	5	3	3	4
37	2	2	4	5
38	5	4	1	2
39	4	4	5	5
40	4	5	3	1
41	3	3	3	3
42	4	3	4	5
43	3	3	4	3
<i>SUM</i>	<i>164</i>	<i>136</i>	<i>146</i>	<i>172</i>
<i>SQUARE</i>	<i>660</i>	<i>480</i>	<i>544</i>	<i>746</i>
<i>MEAN</i>	<i>3.81</i>	<i>3.16</i>	<i>3.4</i>	<i>4</i>
<i>SD</i>	<i>0.91</i>	<i>1.09</i>	<i>1.07</i>	<i>1.18</i>
<i>SD ERROR</i>	<i>0.14</i>	<i>0.17</i>	<i>0.16</i>	<i>0.18</i>

Table 6.33-A Survey result for four treatments A, B, C, and D (Question #7)

# of Sample	A	B	C	D
1	5	5	3	2
2	2	3	4	1
3	4	2	5	3
4	3	5	4	4
5	4	5	5	3
6	4	4	4	4
7	4	3	5	2
8	5	5	5	5
9	4	2	5	3
10	2	4	1	3
11	4	2	5	3
12	4	4	4	4
13	4	5	5	5
14	2	5	4	3
15	4	2	5	1
16	5	3	1	4
17	4	2	5	3
18	5	3	2	4
19	5	5	5	3
20	4	2	5	3
21	4	4	5	5
22	5	5	5	4
23	5	3	4	2
24	4	3	4	3
25	4	3	5	2
26	2	4	5	3
27	5	5	5	4
28	2	5	4	3
29	3	4	5	3
30	2	3	5	4
31	4	3	4	2
32	2	3	4	5

33	3	5	4	2
34	5	3	4	2
35	3	5	4	3
36	4	4	5	3
37	4	2	5	2
38	1	5	2	4
39	4	4	5	4
40	4	5	1	3
41	3	3	2	3
42	5	4	5	3
43	4	3	3	3
<i>SUM</i>	<i>160</i>	<i>159</i>	<i>177</i>	<i>135</i>
<i>SQUARE</i>	<i>644</i>	<i>639</i>	<i>791</i>	<i>465</i>
<i>MEAN</i>	<i>3.72</i>	<i>3.7</i>	<i>4.12</i>	<i>3.14</i>
<i>SD</i>	<i>1.08</i>	<i>1.1</i>	<i>1.22</i>	<i>0.99</i>
<i>SD ERROR</i>	<i>0.16</i>	<i>0.17</i>	<i>0.19</i>	<i>0.15</i>

Table 6.34-A Survey result for four treatments A, B, C, and D (Question #8)

# of Sample	A	B	C	D
1	3	5	3	2
2	2	3	4	1
3	5	4	4	2
4	3	5	4	4
5	5	5	5	5
6	4	4	4	4
7	4	5	2	3
8	4	4	4	5
9	4	2	5	3
10	2	4	1	3
11	4	2	5	3
12	4	4	4	3
13	4	5	4	5
14	3	5	2	4
15	3	4	5	2
16	5	4	1	3
17	3	2	5	4
18	5	4	5	3
19	5	5	5	3
20	3	5	4	2
21	4	4	5	5
22	3	5	5	3
23	4	3	5	2
24	4	3	4	3
25	4	2	5	3
26	2	5	3	4
27	5	4	5	4
28	2	5	4	3
29	5	4	3	3
30	3	4	5	2
31	2	5	3	2
32	2	3	4	5
33	2	5	3	4
34	3	5	2	4
35	4	4	4	4
36	3	4	4	5
37	4	2	5	2
38	1	5	2	4
39	5	4	5	3
40	3	5	1	4
41	5	4	4	3
42	3	3	3	3
<i>SUM</i>	<i>148</i>	<i>169</i>	<i>160</i>	<i>139</i>
<i>SQUARE</i>	<i>570</i>	<i>721</i>	<i>672</i>	<i>503</i>
<i>MEAN</i>	<i>3.52</i>	<i>4.02</i>	<i>3.81</i>	<i>3.31</i>
<i>SD</i>	<i>1.09</i>	<i>1</i>	<i>1.23</i>	<i>1.02</i>
<i>SD ERROR</i>	<i>0.17</i>	<i>0.15</i>	<i>0.19</i>	<i>0.16</i>

Table 6.35-A Survey result for four treatments A, B, C, and D (Question #9)

# of Sample	A	B	C	D
1	1	3	2	1
2	2	3	4	1
3	5	2	4	3
4	4	3	5	3
5	4	5	5	3
6	4	4	4	4
7	3	4	2	5
8	4	4	3	5
9	5	3	4	2
10	2	4	1	3
11	3	2	4	5
12	4	4	5	5
13	4	4	5	5
14	2	5	4	3
15	2	4	5	3
16	5	4	1	3
17	3	5	4	2
18	3	4	5	3
19	2	5	5	3
20	2	5	4	3
21	4	4	5	5
22	4	5	4	5
23	4	3	5	2
24	4	3	4	3
25	3	4	2	5
26	2	4	5	3
27	4	5	4	5
28	2	3	5	4
29	5	3	4	3
30	2	4	5	3
31	4	2	3	1
32	3	4	5	2
33	4	3	5	2
34	5	2	4	3
35	2	5	4	4
36	5	2	4	3
37	4	2	5	2
38	1	4	5	3
39	4	5	5	4
40	4	5	1	3
41	5	4	4	3
42	4	4	4	4
<i>SUM</i>	<i>143</i>	<i>157</i>	<i>168</i>	<i>137</i>
<i>SQUARE</i>	<i>543</i>	<i>627</i>	<i>730</i>	<i>503</i>
<i>MEAN</i>	<i>3.4</i>	<i>3.74</i>	<i>4</i>	<i>3.26</i>
<i>SD</i>	<i>1.17</i>	<i>0.99</i>	<i>1.19</i>	<i>1.17</i>
<i>SD ERROR</i>	<i>0.18</i>	<i>0.15</i>	<i>0.18</i>	<i>0.18</i>

Table 6.36-A Survey result for four treatments A, B, C, and D (Question #10)

# of Sample	A	B	C	D
1	1	1	1	1
2	2	3	4	1
3	3	5	2	4
4	3	3	5	4
5	4	4	5	4
6	4	4	4	4
7	4	2	3	5
8	2	2	2	5
9	2	3	4	5
10	2	4	1	3
11	5	2	4	3
12	3	3	3	4
13	4	4	5	5
14	4	3	5	2
15	2	4	3	5
16	5	4	1	3
17	3	5	4	2
18	3	3	3	3
19	5	5	5	2
20	3	4	5	2
21	4	4	5	5
22	5	4	4	5
23	4	2	5	3
24	4	2	4	2
25	2	4	3	5
26	2	5	3	4
27	5	5	4	4
28	3	4	5	2
29	3	4	5	2
30	2	5	3	4
31	2	2	3	2
32	3	4	5	2
33	3	5	2	4
34	3	4	2	5
35	4	4	5	4
36	4	3	5	5
37	4	2	5	2
38	1	5	2	4
39	4	5	5	4
40	4	3	1	5
41	4	4	5	3
42	2	2	2	2
<i>SUM</i>	<i>136</i>	<i>150</i>	<i>152</i>	<i>145</i>
<i>SQUARE</i>	<i>490</i>	<i>586</i>	<i>628</i>	<i>567</i>
<i>MEAN</i>	<i>3.24</i>	<i>3.57</i>	<i>3.62</i>	<i>3.45</i>
<i>SD</i>	<i>1.1</i>	<i>1.11</i>	<i>1.38</i>	<i>1.27</i>
<i>SD ERROR</i>	<i>0.17</i>	<i>0.17</i>	<i>0.21</i>	<i>0.2</i>

Table 6.37-A Survey result for two treatments A and B (Question #11)

# of Sample	A	B
1	4	5
2	4	5
3	4	5
4	3	5
5	5	5
6	4	4
7	5	5
8	4	5
9	4	5
10	5	5
11	3	5
12	4	3
13	4	5
14	1	1
15	3	2
16	4	4
17	5	5
18	5	5
19	4	5
20	3	5
21	4	4
22	5	5
23	4	4
24	3	4
25	4	5
26	4	4
27	5	5
28	5	3
29	3	4
30	4	5
31	5	5
32	4	5

33	3	4
34	3	4
35	4	5
36	4	3
37	4	2
38	4	5
39	4	5
40	5	5
41	4	4
42	3	3
<i>SUM</i>	<i>166</i>	<i>182</i>
<i>SQUARE</i>	<i>684</i>	<i>830</i>
<i>MEAN</i>	<i>3.95</i>	<i>4.33</i>
<i>SD</i>	<i>0.82</i>	<i>1</i>
<i>SD ERROR</i>	<i>0.13</i>	<i>0.15</i>

Table 6.38-A Survey result for two treatments A and B (Question #12)

# of Sample	A	B
1	3	5
2	4	5
3	3	5
4	3	5
5	4	5
6	4	4
7	5	5
8	4	5
9	4	5
10	5	5
11	3	5
12	3	3
13	4	5
14	2	2
15	5	4
16	4	4
17	4	5
18	5	5
19	5	5
20	3	5
21	3	3
22	5	5
23	5	5
24	3	4
25	4	5
26	4	5
27	5	5
28	5	3
29	3	5
30	4	5
31	4	5
32	4	5

33	3	4
34	5	4
35	4	4
36	2	5
37	3	3
38	4	5
39	5	5
40	5	4
41	4	5
42	4	4
<i>SUM</i>	<i>165</i>	<i>190</i>
<i>SQUARE</i>	<i>679</i>	<i>884</i>
<i>MEAN</i>	<i>3.93</i>	<i>4.52</i>
<i>SD</i>	<i>0.87</i>	<i>0.77</i>
<i>SD ERROR</i>	<i>0.13</i>	<i>0.12</i>

Table 6.39-A Survey result for three treatments A and B (Question #13)

# of Sample	A	B
1	3	5
2	3	3
3	3	4
4	2	5
5	4	5
6	4	4
7	4	5
8	3	5
9	5	4
10	3	3
11	4	5
12	4	4
13	4	5
14	3	3
15	4	3
16	4	3
17	4	5
18	3	4
19	5	5
20	4	5
21	4	5
22	5	5
23	4	4
24	3	3
25	4	5
26	4	5
27	4	5
28	2	5
29	4	5
30	4	5
31	3	4
32	4	5

33	4	4
34	4	5
35	4	4
36	3	4
37	2	4
38	4	5
39	4	5
40	3	5
41	4	5
42	5	5
<i>SUM</i>	<i>155</i>	<i>187</i>
<i>SQUARE</i>	<i>595</i>	<i>855</i>
<i>MEAN</i>	<i>3.69</i>	<i>4.45</i>
<i>SD</i>	<i>0.75</i>	<i>0.74</i>
<i>SD ERROR</i>	<i>0.12</i>	<i>0.11</i>

Survey Results for Transdisciplinary Research Objectives (Group: Graduates)

Table 6.40-A Survey result for three treatments A, B, and C (Question #1)

# of Sample	A	B	C
1	5	5	5
2	5	3	1
3	5	4	3
4	5	4	4
5	4	3	2
6	5	5	3
7	4	3	5
8	5	4	5
9	4	4	5
10	5	3	4
11	4	5	4
12	5	3	4
13	5	4	3
14	5	4	5
15	3	3	3
16	3	4	5
17	5	3	5
18	2	1	3
19	4	2	5
20	5	4	4
21	5	4	3
22	5	3	4
23	5	5	5
24	4	2	3
25	4	3	4
<i>SUM</i>	<i>111</i>	<i>88</i>	<i>97</i>
<i>SQUARE</i>	<i>509</i>	<i>334</i>	<i>405</i>
<i>MEAN</i>	<i>4.44</i>	<i>3.52</i>	<i>3.88</i>
<i>SD</i>	<i>0.82</i>	<i>1.00</i>	<i>1.09</i>
<i>SD ERROR</i>	<i>0.16</i>	<i>0.20</i>	<i>0.22</i>

Table 6.41-A Survey result for three treatments A, B, and C (Question #2)

# of Sample	A	B	C
1	5	5	5
2	1	3	5
3	5	4	4
4	5	3	3
5	5	2	4
6	5	5	3
7	3	4	5
8	5	4	5
9	4	3	5
10	5	4	3
11	4	5	4
12	5	3	4
13	5	3	4
14	5	5	5
15	3	4	3
16	2	3	1
17	4	5	3
18	3	1	5
19	4	2	5
20	5	3	5
21	4	3	5
22	5	3	4
23	5	4	5
24	4	2	3
25	3	4	4
<i>SUM</i>	<i>104</i>	<i>87</i>	<i>102</i>
<i>SQUARE</i>	<i>462</i>	<i>331</i>	<i>442</i>
<i>MEAN</i>	<i>4.16</i>	<i>3.48</i>	<i>4.08</i>
<i>SD</i>	<i>1.11</i>	<i>1.08</i>	<i>1.04</i>
<i>SD ERROR</i>	<i>0.22</i>	<i>0.22</i>	<i>0.21</i>

Table 6.42-A Survey result for three treatments A, B, and C (Question #3)

# of Sample	A	B	C
1	5	5	5
2	1	3	5
3	5	5	5
4	5	5	4
5	5	4	4
6	5	5	3
7	4	3	5
8	4	4	5
9	4	4	4
10	5	3	3
11	5	4	4
12	5	4	5
13	5	4	3
14	4	4	4
15	3	4	4
16	1	2	3
17	5	5	5
18	3	1	4
19	4	3	5
20	5	4	5
21	4	3	5
22	4	5	3
23	5	4	5
24	3	5	4
25	4	3	3
<i>SUM</i>	<i>103</i>	<i>96</i>	<i>105</i>
<i>SQUARE</i>	<i>457</i>	<i>394</i>	<i>457</i>
<i>MEAN</i>	<i>4.12</i>	<i>3.84</i>	<i>4.20</i>
<i>SD</i>	<i>1.17</i>	<i>1.03</i>	<i>0.82</i>
<i>SD ERROR</i>	<i>0.23</i>	<i>0.21</i>	<i>0.16</i>

Table 6.43-A Survey result for three treatments A, B, and C (Question #4)

# of Sample	A	B	C
1	5	5	5
2	3	5	1
3	4	4	4
4	5	4	3
5	5	5	5
6	5	5	3
7	3	5	4
8	5	5	3
9	3	3	4
10	5	5	4
11	5	4	4
12	5	4	5
13	4	3	5
14	4	4	4
15	4	4	4
16	2	3	1
17	5	4	2
18	4	2	1
19	4	3	5
20	4	5	3
21	5	4	3
22	4	5	3
23	5	4	5
24	3	5	4
25	4	4	3
<i>SUM</i>	<i>105</i>	<i>104</i>	<i>88</i>
<i>SQUARE</i>	<i>459</i>	<i>450</i>	<i>348</i>
<i>MEAN</i>	<i>4.20</i>	<i>4.16</i>	<i>3.52</i>
<i>SD</i>	<i>0.87</i>	<i>0.85</i>	<i>1.26</i>
<i>SD ERROR</i>	<i>0.17</i>	<i>0.17</i>	<i>0.25</i>

Table 6.44-A Survey result for four treatments A, B, C, and D (Question #5)

# of Sample	A	B	C	D
1	4	4	4	4
2	5	3	1	4
3	4	5	3	4
4	4	5	2	3
5	4	4	5	5
6	5	5	5	3
7	3	4	5	1
8	4	5	4	5
9	4	2	3	2
10	3	3	4	5
11	4	5	4	3
12	4	3	5	2
13	5	5	5	4
14	2	3	4	4
15	1	4	2	3
16	1	4	5	4
17	1	3	4	2
18	3	4	1	2
19	4	5	4	4
20	2	4	3	5
21	5	4	3	2
22	4	4	5	2
23	4	3	5	2
24	4	4	3	3
<i>SUM</i>	<i>84</i>	<i>95</i>	<i>89</i>	<i>78</i>
<i>SQUARE</i>	<i>330</i>	<i>393</i>	<i>367</i>	<i>286</i>
<i>MEAN</i>	<i>3.50</i>	<i>3.96</i>	<i>3.71</i>	<i>3.25</i>
<i>SD</i>	<i>1.25</i>	<i>0.86</i>	<i>1.27</i>	<i>1.19</i>
<i>SD ERROR</i>	<i>0.26</i>	<i>0.18</i>	<i>0.26</i>	<i>0.24</i>

Table 6.45-A Survey result for four treatments A, B, C, and D (Question #6)

# of Sample	A	B	C	D
1	4	4	4	4
2	3	1	4	5
3	5	4	4	3
4	5	4	4	3
5	4	3	4	5
6	5	4	5	5
7	4	1	3	5
8	5	4	4	4
9	2	2	4	3
10	5	4	3	4
11	5	4	5	4
12	2	4	3	5
13	5	4	5	5
14	5	4	3	3
15	4	1	2	3
16	3	5	2	5
17	3	2	1	4
18	5	4	2	3
19	5	3	3	5
20	5	4	2	3
21	5	2	4	3
22	4	2	4	5
23	2	4	3	5
24	4	3	4	3
<i>SUM</i>	<i>99</i>	<i>77</i>	<i>82</i>	<i>97</i>
<i>SQUARE</i>	<i>435</i>	<i>279</i>	<i>306</i>	<i>411</i>
<i>MEAN</i>	<i>4.13</i>	<i>3.21</i>	<i>3.42</i>	<i>4.04</i>
<i>SD</i>	<i>1.08</i>	<i>1.18</i>	<i>1.06</i>	<i>0.91</i>
<i>SD ERROR</i>	<i>0.22</i>	<i>0.24</i>	<i>0.22</i>	<i>0.19</i>

Table 6.46-A Survey result for four treatments A, B, C, and D (Question #7)

# of Sample	A	B	C	D
1	5	5	5	5
2	4	3	5	1
3	4	5	3	4
4	5	4	5	3
5	2	4	5	3
6	5	2	5	2
7	5	1	4	3
8	4	5	4	4
9	3	2	4	2
10	3	5	4	4
11	4	5	4	4
12	5	2	3	4
13	4	4	4	4
14	4	3	3	3
15	3	1	4	2
16	2	5	4	4
17	1	3	4	2
18	3	4	5	2
19	5	4	5	3
20	5	3	2	4
21	3	5	4	2
22	4	4	5	2
23	4	3	5	2
24	4	4	4	3
<i>SUM</i>	<i>91</i>	<i>86</i>	<i>100</i>	<i>72</i>
<i>SQUARE</i>	<i>373</i>	<i>346</i>	<i>432</i>	<i>240</i>
<i>MEAN</i>	<i>3.79</i>	<i>3.58</i>	<i>4.17</i>	<i>3.00</i>
<i>SD</i>	<i>1.10</i>	<i>1.28</i>	<i>0.82</i>	<i>1.02</i>
<i>SD ERROR</i>	0.23	0.26	0.17	0.21

Table 6.47-A Survey result for four treatments A, B, C, and D (Question #8)

# of Sample	A	B	C	D
1	4	4	4	4
2	4	3	1	5
3	4	5	4	5
4	5	3	5	2
5	2	4	3	5
6	5	5	5	3
7	4	3	5	1
8	4	5	4	5
9	3	2	3	2
10	3	5	4	3
11	4	5	4	4
12	5	3	2	4
13	4	4	4	4
14	3	4	4	4
15	2	4	3	1
16	2	5	3	4
17	2	3	4	1
18	2	3	1	4
19	4	5	5	4
20	3	4	2	5
21	4	5	2	3
22	4	4	5	3
23	3	5	4	2
24	4	4	4	3
<i>SUM</i>	<i>84</i>	<i>97</i>	<i>85</i>	<i>81</i>
<i>SQUARE</i>	<i>316</i>	<i>411</i>	<i>335</i>	<i>313</i>
<i>MEAN</i>	<i>3.50</i>	<i>4.04</i>	<i>3.54</i>	<i>3.38</i>
<i>SD</i>	<i>0.98</i>	<i>0.91</i>	<i>1.22</i>	<i>1.31</i>
<i>SD ERROR</i>	0.20	0.19	0.25	0.27

Table 6.48-A Survey result for four treatments A, B, C, and D (Question #9)

# of Sample	A	B	C	D
1	4	4	4	4
2	3	1	4	5
3	4	5	3	4
4	4	3	4	3
5	3	4	5	2
6	5	5	5	2
7	3	5	4	1
8	4	5	4	4
9	2	1	2	1
10	3	5	4	3
11	4	5	4	5
12	4	2	5	3
13	4	4	4	4
14	2	2	4	2
15	3	2	4	1
16	2	2	4	5
17	2	3	4	1
18	2	3	1	4
19	5	2	5	2
20	3	2	5	4
21	2	4	5	3
22	4	4	5	3
23	3	2	5	4
24	4	4	3	3
<i>SUM</i>	<i>79</i>	<i>79</i>	<i>97</i>	<i>73</i>
<i>SQUARE</i>	<i>281</i>	<i>303</i>	<i>415</i>	<i>261</i>
<i>MEAN</i>	<i>3.29</i>	<i>3.29</i>	<i>4.04</i>	<i>3.04</i>
<i>SD</i>	<i>0.95</i>	<i>1.37</i>	<i>1.00</i>	<i>1.30</i>
<i>SD ERROR</i>	<i>0.19</i>	<i>0.28</i>	<i>0.20</i>	<i>0.27</i>

Table 6.49-A1 Survey result for four treatments A, B, C, and D (Question #10)

# of Sample	A	B	C	D
1	5	5	5	5
2	4	3	1	5
3	5	4	4	4
4	4	5	3	3
5	5	3	4	2
6	5	5	5	5
7	3	4	5	1
8	5	5	4	4
9	3	2	2	1
10	3	5	4	3
11	5	5	5	5
12	2	4	3	5
13	4	4	4	4
14	2	4	5	4
15	4	2	3	1
16	2	5	2	4
17	2	3	4	1
18	2	1	3	4
19	5	2	5	3
20	3	2	5	4
21	2	4	5	3
22	4	4	5	3
23	2	4	5	3
24	4	4	3	3
<i>SUM</i>	<i>85</i>	<i>89</i>	<i>94</i>	<i>80</i>
<i>SQUARE</i>	<i>335</i>	<i>363</i>	<i>400</i>	<i>308</i>
<i>MEAN</i>	<i>3.54</i>	<i>3.71</i>	<i>3.92</i>	<i>3.33</i>
<i>SD</i>	<i>1.22</i>	<i>1.20</i>	<i>1.18</i>	<i>1.34</i>
<i>SD ERROR</i>	<i>0.25</i>	<i>0.24</i>	<i>0.24</i>	<i>0.27</i>

Table 6.50-A Survey result for two treatments A and B (Question #11)

# of Sample	A	B
1	5	5
2	3	3
3	3	3
4	3	5
5	4	5
6	5	5
7	4	5
8	4	5
9	4	4
10	5	5
11	5	5
12	3	5
13	5	5
14	5	5
15	4	5
16	2	5
17	4	5
18	3	4
19	3	4
20	3	5
21	5	5
22	3	4
23	4	5
24	4	4
<i>SUM</i>	<i>93</i>	<i>111</i>
<i>SQUARE</i>	<i>379</i>	<i>523</i>
<i>MEAN</i>	<i>3.88</i>	<i>4.63</i>
<i>SD</i>	<i>0.90</i>	<i>0.65</i>
<i>SD ERROR</i>	<i>0.18</i>	<i>0.13</i>

Table 6.51-A Survey result for two treatments A and B (Question #12)

# of Sample	A	B
1	4	4
2	3	5
3	4	5
4	3	5
5	4	5
6	3	5
7	4	5
8	4	4
9	4	4
10	5	5
11	5	5
12	3	5
13	4	5
14	4	4
15	4	4
16	4	4
17	3	4
18	3	4
19	3	5
20	3	5
21	5	5
22	5	5
23	4	5
24	3	3
<i>SUM</i>	<i>91</i>	<i>110</i>
<i>SQUARE</i>	<i>357</i>	<i>512</i>
<i>MEAN</i>	<i>3.79</i>	<i>4.58</i>
<i>SD</i>	<i>0.72</i>	<i>0.58</i>
<i>SD ERROR</i>	<i>0.15</i>	<i>0.12</i>

Table 6.52-A Survey result for two treatments A and B (Question #13)

# of Sample	A	B
1	5	5
2	1	5
3	3	3
4	3	4
5	4	5
6	3	5
7	4	5
8	4	5
9	4	4
10	5	5
11	5	5
12	3	5
13	4	5
14	3	3
15	4	3
16	4	4
17	4	4
18	3	4
19	3	5
20	4	5
21	4	5
22	5	5
23	4	5
24	4	4
<i>SUM</i>	<i>90</i>	<i>108</i>
<i>SQUARE</i>	<i>356</i>	<i>498</i>
<i>MEAN</i>	<i>3.75</i>	<i>4.50</i>
<i>SD</i>	<i>0.90</i>	<i>0.72</i>
<i>SD ERROR</i>	<i>0.18</i>	<i>0.15</i>

Randomly selected samples for Comparison of Interdisciplinary and Transdisciplinary Research (Group: Academics)

Table 6.53-A Survey result for two treatments A and B (Question #11)

# of Sample	A	B
1	5	5
2	3	5
3	4	4
4	4	4
5	3	5
6	5	5
7	4	5
8	5	4
9	5	5
10	4	5
11	5	5
12	5	5
13	5	5
14	4	5
15	3	3
16	4	5
17	3	4
18	4	5
19	2	5
20	5	4
21	4	5
22	5	5
23	4	5
24	4	4
25	5	4
26	3	5
27	4	5
28	5	5
<i>SUM</i>	<i>116</i>	<i>131</i>
<i>SQUARE</i>	<i>500</i>	<i>621</i>
<i>MEAN</i>	<i>4.14</i>	<i>4.68</i>
<i>SD</i>	<i>0.85</i>	<i>0.55</i>
<i>SD ERROR</i>	<i>0.15</i>	<i>0.10</i>

Table 6.54-A Survey result for two treatments A and B (Question #12)

# of Sample	A	B
1	4	5
2	4	5
3	3	4
4	5	5
5	3	5
6	2	2
7	4	5
8	4	5
9	3	3
10	5	4
11	5	5
12	4	4
13	5	5
14	3	5
15	2	2
16	4	5
17	3	4
18	3	5
19	3	5
20	3	5
21	3	5
22	4	5
23	3	5
24	4	4
25	4	5
26	4	5
27	4	5
28	5	5
<i>SUM</i>	<i>103</i>	<i>127</i>
<i>SQUARE</i>	<i>399</i>	<i>597</i>
<i>MEAN</i>	<i>3.68</i>	<i>4.54</i>
<i>SD</i>	<i>0.86</i>	<i>0.88</i>
<i>SD ERROR</i>	<i>0.15</i>	<i>0.15</i>

Table 6.55-A Survey result for two treatments A and B (Question #13)

# of Sample	A	B
1	4	5
2	4	5
3	5	5
4	4	4
5	3	5
6	2	5
7	5	4
8	4	5
9	4	4
10	4	5
11	5	5
12	5	4
13	5	5
14	4	4
15	4	4
16	4	5
17	3	4
18	2	5
19	3	5
20	2	5
21	4	5
22	4	5
23	4	5
24	4	4
25	4	5
26	3	5
27	4	5
28	5	5
<i>SUM</i>	<i>108</i>	<i>132</i>
<i>SQUARE</i>	<i>438</i>	<i>628</i>
<i>MEAN</i>	<i>3.86</i>	<i>4.71</i>
<i>SD</i>	<i>0.89</i>	<i>0.46</i>
<i>SD ERROR</i>	<i>0.16</i>	<i>0.08</i>

Randomly selected samples for Comparison of Interdisciplinary and Transdisciplinary Research (Group: Industry)

Table 6.56-A Survey result for two treatments A and B (Question #11)

# of Sample	A	B
1	4	5
2	4	5
3	3	5
4	4	4
5	5	5
6	4	5
7	4	5
8	3	5
9	4	3
10	4	5
11	1	1
12	5	5
13	4	5
14	3	5
15	4	4
16	3	4
17	4	5
18	4	4
19	4	5
20	4	5
21	3	4
22	4	5
23	4	3
24	4	2
25	4	5
26	5	5
27	4	4
28	3	3
<i>SUM</i>	<i>106</i>	<i>121</i>
<i>SQUARE</i>	<i>418</i>	<i>553</i>
<i>MEAN</i>	<i>3.79</i>	<i>4.32</i>
<i>SD</i>	<i>0.79</i>	<i>1.06</i>
<i>SD ERROR</i>	<i>0.12</i>	<i>0.16</i>

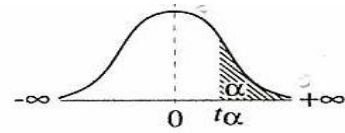
Table 6.57-A Survey result for two treatments A and B (Question #12)

# of Sample	A	B
1	3	5
2	3	5
3	3	5
4	4	4
5	5	5
6	4	5
7	4	5
8	3	5
9	3	3
10	4	5
11	2	2
12	4	5
13	5	5
14	3	5
15	3	3
16	3	4
17	4	5
18	4	5
19	4	5
20	4	5
21	5	4
22	4	4
23	2	5
24	3	3
25	4	5
26	5	4
27	4	5
28	4	4
<i>SUM</i>	<i>103</i>	<i>125</i>
<i>SQUARE</i>	<i>397</i>	<i>577</i>
<i>MEAN</i>	<i>3.68</i>	<i>4.46</i>
<i>SD</i>	<i>0.82</i>	<i>0.84</i>
<i>SD ERROR</i>	<i>0.13</i>	<i>0.13</i>

Table 6.58-A Survey result for two treatments A and B (Question #13)

# of Sample	A	B
1	3	5
2	3	4
3	2	5
4	4	4
5	4	5
6	3	5
7	5	4
8	4	5
9	4	4
10	4	5
11	3	3
12	4	5
13	5	5
14	4	5
15	4	5
16	3	3
17	4	5
18	4	5
19	4	5
20	4	5
21	4	5
22	4	4
23	3	4
24	2	4
25	4	5
26	3	5
27	4	5
28	5	5
<i>SUM</i>	<i>104</i>	<i>129</i>
<i>SQUARE</i>	<i>402</i>	<i>605</i>
<i>MEAN</i>	<i>3.71</i>	<i>4.61</i>
<i>SD</i>	<i>0.76</i>	<i>0.63</i>
<i>SD ERROR</i>	<i>0.12</i>	<i>0.10</i>

APPENDIX B

Table C.2 Critical Values of the t Distribution**Table C.2** Critical Values of the t Distribution^a

$\nu =$ $n - 1$	α				
	0.10	0.05	0.025	0.01	0.005
1	3.078	6.314	12.706	31.821	63.657
2	1.886	2.920	4.303	6.965	9.925
3	1.638	2.353	3.182	4.541	5.841
4	1.533	2.132	2.776	3.747	4.604
5	1.476	2.015	2.571	3.365	4.032
6	1.440	1.943	2.447	3.143	3.707
7	1.415	1.895	2.365	2.998	3.499
8	1.397	1.860	2.306	2.896	3.355
9	1.383	1.833	2.262	2.821	3.250
10	1.372	1.812	2.228	2.764	3.169
11	1.363	1.796	2.201	2.718	3.106
12	1.356	1.782	2.179	2.681	3.055
13	1.350	1.771	2.160	2.650	3.012
14	1.345	1.761	2.145	2.624	2.977
15	1.341	1.753	2.131	2.602	2.947
16	1.337	1.746	2.120	2.583	2.921
17	1.333	1.740	2.110	2.567	2.898
18	1.330	1.734	2.101	2.552	2.878
19	1.328	1.729	2.093	2.539	2.861
20	1.325	1.725	2.086	2.528	2.854
21	1.323	1.721	2.080	2.518	2.831
22	1.321	1.717	2.074	2.508	2.819
23	1.319	1.714	2.069	2.500	2.807
24	1.318	1.711	2.064	2.492	2.797
25	1.316	1.708	2.060	2.485	2.787
26	1.315	1.706	2.056	2.479	2.779
27	1.314	1.703	2.052	2.473	2.771
28	1.313	1.701	2.048	2.467	2.763
29	1.311	1.699	2.045	2.462	2.756
inf.	1.282	1.645	1.960	2.326	2.576

^aFrom R. A. Fisher, "Statistical Methods for Research Workers," published by Oliver & Boyd, Edinburgh. Copyright ©1970 University of Adelaide.

Table C.4 Degrees of Freedom for the Numerator (ν_1) F .025, ν_1 , ν_2

		$F_{0.05, \nu_1, \nu_2}$																		
		Degrees of Freedom for the Numerator (ν_1)																		
ν_2	ν_1	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
1	647.8	799.5	864.2	899.6	921.8	937.1	948.2	956.7	963.3	968.6	976.7	984.9	993.1	997.2	1001	1006	1010	1014	1018	
2	38.51	39.00	39.17	39.25	39.30	39.33	39.36	39.37	39.39	39.40	39.41	39.43	39.45	39.46	39.46	39.47	39.48	39.49	39.50	
3	17.44	16.04	15.44	15.10	14.88	14.73	14.62	14.54	14.47	14.42	14.34	14.25	14.17	14.12	14.08	14.04	13.99	13.95	13.90	
4	12.22	10.65	9.98	9.60	9.36	9.20	9.07	8.98	8.90	8.84	8.75	8.66	8.56	8.51	8.46	8.41	8.36	8.31	8.26	
5	10.01	8.43	7.76	7.39	7.15	6.98	6.85	6.76	6.68	6.62	6.52	6.43	6.33	6.28	6.23	6.18	6.12	6.07	6.02	
6	8.81	7.26	6.60	6.23	5.99	5.82	5.70	5.60	5.52	5.46	5.37	5.27	5.17	5.12	5.07	5.01	4.96	4.90	4.85	
7	8.07	6.54	5.89	5.52	5.29	5.12	4.99	4.90	4.82	4.76	4.67	4.57	4.47	4.42	4.36	4.31	4.25	4.20	4.14	
8	7.57	6.06	5.42	5.05	4.82	4.65	4.53	4.43	4.36	4.30	4.20	4.10	4.00	3.95	3.89	3.84	3.78	3.73	3.67	
9	7.21	5.71	5.08	4.72	4.48	4.32	4.20	4.10	4.03	3.96	3.87	3.77	3.67	3.61	3.56	3.51	3.45	3.39	3.33	
10	6.94	5.46	4.83	4.47	4.24	4.07	3.95	3.85	3.78	3.72	3.62	3.52	3.42	3.37	3.31	3.26	3.20	3.14	3.08	
11	6.72	5.26	4.63	4.28	4.04	3.88	3.76	3.66	3.59	3.53	3.43	3.33	3.23	3.17	3.12	3.06	3.00	2.94	2.88	
12	6.55	5.10	4.47	4.12	3.89	3.73	3.61	3.51	3.44	3.37	3.28	3.18	3.07	3.02	2.96	2.91	2.85	2.79	2.72	
13	6.41	4.97	4.35	4.00	3.77	3.60	3.48	3.39	3.31	3.25	3.15	3.05	2.95	2.89	2.84	2.78	2.72	2.66	2.60	
14	6.30	4.86	4.24	3.89	3.66	3.50	3.38	3.29	3.21	3.15	3.05	2.95	2.84	2.79	2.73	2.67	2.61	2.55	2.49	
15	6.20	4.77	4.15	3.80	3.58	3.41	3.29	3.20	3.12	3.06	2.96	2.86	2.76	2.70	2.64	2.59	2.52	2.46	2.40	
16	6.12	4.69	4.08	3.73	3.50	3.34	3.22	3.12	3.05	2.99	2.89	2.79	2.68	2.63	2.57	2.51	2.45	2.38	2.32	
17	6.04	4.62	4.01	3.66	3.44	3.28	3.16	3.06	2.98	2.92	2.82	2.72	2.62	2.56	2.50	2.44	2.38	2.32	2.25	
18	5.98	4.56	3.95	3.61	3.38	3.22	3.10	3.01	2.93	2.87	2.77	2.67	2.56	2.50	2.44	2.38	2.32	2.26	2.19	
19	5.92	4.51	3.90	3.56	3.33	3.17	3.05	2.96	2.88	2.82	2.72	2.62	2.51	2.45	2.39	2.33	2.27	2.20	2.13	

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Table C4, (Continued)

		$F_{.025, \nu_1, \nu_2}$																		
		Degrees of Freedom for the Numerator (ν_1)																		
ν_2	ν_1	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
20		5.87	4.46	3.86	3.51	3.29	3.13	3.01	2.91	2.84	2.77	2.68	2.57	2.46	2.41	2.35	2.29	2.22	2.16	2.09
21		5.83	4.42	3.82	3.48	3.25	3.09	2.97	2.87	2.80	2.73	2.64	2.53	2.42	2.37	2.31	2.25	2.18	2.11	2.04
22		5.79	4.38	3.78	3.44	3.22	3.05	2.93	2.84	2.76	2.70	2.60	2.50	2.39	2.33	2.27	2.21	2.14	2.08	2.00
23		5.75	4.35	3.75	3.41	3.18	3.02	2.90	2.81	2.73	2.67	2.57	2.47	2.36	2.30	2.24	2.18	2.11	2.04	1.97
24		5.72	4.32	3.72	3.38	3.15	2.99	2.87	2.78	2.70	2.64	2.54	2.44	2.33	2.27	2.21	2.15	2.08	2.01	1.94
25		5.69	4.29	3.69	3.35	3.13	2.97	2.85	2.75	2.68	2.61	2.51	2.41	2.30	2.24	2.18	2.12	2.05	1.98	1.91
26		5.66	4.27	3.67	3.33	3.10	2.94	2.82	2.73	2.65	2.59	2.49	2.39	2.28	2.22	2.16	2.09	2.03	1.95	1.88
27		5.63	4.24	3.65	3.31	3.08	2.92	2.80	2.71	2.63	2.57	2.47	2.36	2.25	2.19	2.13	2.07	2.00	1.93	1.85
28		5.61	4.22	3.63	3.29	3.06	2.90	2.78	2.69	2.61	2.55	2.45	2.34	2.23	2.17	2.11	2.05	1.98	1.91	1.83
29		5.59	4.20	3.61	3.27	3.04	2.88	2.76	2.67	2.59	2.53	2.43	2.32	2.21	2.15	2.09	2.03	1.96	1.89	1.81
30		5.57	4.18	3.59	3.25	3.03	2.87	2.75	2.65	2.57	2.51	2.41	2.31	2.20	2.14	2.07	2.01	1.94	1.87	1.79
40		5.42	4.05	3.46	3.13	2.90	2.74	2.62	2.53	2.45	2.39	2.29	2.18	2.07	2.01	1.94	1.88	1.80	1.72	1.64
60		5.29	3.93	3.34	3.01	2.79	2.63	2.51	2.41	2.33	2.27	2.17	2.06	1.94	1.88	1.82	1.74	1.67	1.58	1.48
120		5.15	3.80	3.23	2.89	2.67	2.52	2.39	2.30	2.22	2.16	2.05	1.94	1.82	1.76	1.69	1.61	1.53	1.43	1.31
∞		5.02	3.69	3.12	2.79	2.57	2.41	2.29	2.19	2.11	2.05	1.94	1.83	1.71	1.64	1.57	1.48	1.39	1.27	1.00