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Editor

ATILA ERTAS

The Academy of Transdisciplinary Learning & Advance Studies

Transdisciplinarity: Bridging Natural Science, Social Science,Humanities & Engineering

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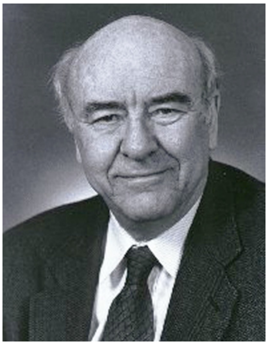
Preface



John Warfield

This book is dedicated to the memory of Professor John Warfield who was a pioneer in system science. Professor Warfield received the Bachelor of Arts in 1948, Bachelor of Science in Electrical Engineering in 1948, and Master of Science in Electrical Engineering in 1949 from the University of Missouri, Columbia, Missouri. He received the Doctor of Philosophy degree from Purdue University, West Lafayette, Indiana in 1952. John Warfield is widely recognized as the father of systems science. He has been an educator, a research scientist in complex systems and organizational dynamics, and a leader in integrating an extensive body of research into an organized hierarchy of systems sciences. Dr. Warfield and his colleagues analyzed complexity and human cognition for over forty years and developed the founding relationships for the still-emerging systems science discipline that underpins significant portions of modern systems engineering. His rich body of work embodies analytical methods and frameworks, behavioral science and philosophies that formalize our understanding of complexity in our world. He holds IEEE Centennial Medal. In 2006 John N. Warfield was awarded the Joseph G. Wohl Award for Career Achievement and in 2007 he received INCOSE Pioneer Award and was also awarded the IEEE Third Millennium Medal.

This book contains accepted papers published in the 2010-Transdisciplinary Journal of Engineering and Science. This book is intended primarily to introduce the tarnsdisciplinarity and its applications in natural science, social science, humanities, and engineering. The editor wishes to aknowledge his indebtedness to his colleagues for the valuable chapters that they have contributed to this book.

Atila Ertas

Remembering* John Warfield

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I will always remember the day John Warfield declared, "I'm taking you to the war room." The "war room" was the famed interdisciplinary think tank on the George Mason University campus where John and his colleagues engaged in integrative design and problem solving. The excitement of their work and other projects is conveyed in the wonderful photo of John, shown in Figure 1, working with a colleague on an early computer (from the Summer 1954 issue of The Pennsylvania State Engineering Review). That memory and others came quickly to mind when I heard that John had passed away on November 17th, 2009, just four days shy of his 84th birthday.

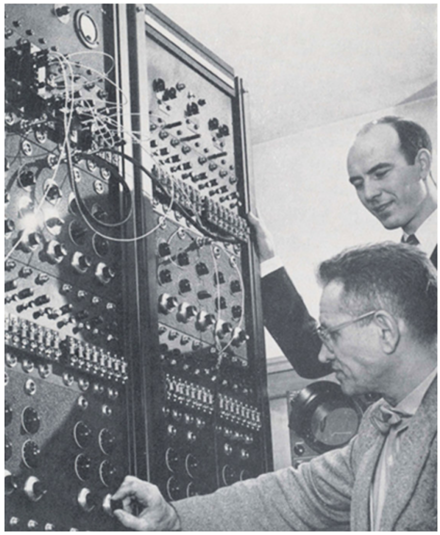

Figure 1.**

John Nelson Warfield was born and grew up in Missouri. When he died, he held the title of University Professor Emeritus and Laureate at George Mason University. Warfield began advanced studies at the University of Missouri but, like many of his generation, found his life interrupted by World War II. After basic training in the U.S. Army Infantry, he was placed in an electrical engineering program. When the war was over, he returned to the Columbia campus in Missouri, where in 1948 he received a

**TheATLAS Publication thanks The Association for Integrative Studies, for permission to reprint and adapt for this special issue remarks previously published in "Remembering John Warfield," AIS Newsletter, 32, 2 (March 2010): 7-8.*

*** TheATLAS Publication thanks Special Collections and Archives and at George Mason University Libraries, for access to the photo with Dr. Warfield (upper right) and a colleague working on an early computer in the 1950's. George Mason University <http://vault217.gmu.edu/?p=1302> and original source The Pennsylvania State Engineering Review, Summer 1954.*

Bachelor of Arts in mathematics and a Bachelor of Science in electrical engineering and in 1949 a Master of Science in electrical engineering. In 1952, he earned a Ph.D in electrical communications from Purdue University. During the course of his career, John held many important positions. He was elected president of the Systems, Man, and Cybernetics Society of the Institute of Electrical and Electronics Engineers (IEEE) and president of the International Society for the Systems Sciences. He was an editor of Systems Research and of the IEEE Transactions on Systems, Man, and Cybernetics. He was also president of Integrative Sciences and the AJAR Publishing Company. Beyond these academic posts, he had ten years of industrial experience and was the author of two U.S. patents on electronic equipment. It comes as no surprise, then, that John was honored in his lifetime. He received the Joseph G. Wohl Award for Career Achievement at the 2006 annual meeting of the IEEE Systems, Man, and Cybernetics Society. The highest award conferred by the Society, it acknowledged his contributions to systems engineering concepts, methodology, design, education and management. In 2007 he also received INCOSE Pioneer Award and the IEEE Third Millennium Medal.

John was not a boastful man, so not one to tout such accomplishments or being called, as he was, "the father of systems science." These qualities were evident to everyone who met him at annual meetings of the Association for Integrative Studies (AIS), a professional organization dedicated to advancing interdisciplinary education. He was a kind and easy-going person who enjoyed a good debate, but also chatting informally with anyone during meals and breaks at AIS conferences. John attended many conferences and was an early proponent of the link between complexity and interdisciplinarity. In 1997, at Appalachian State University, he spoke on "Seven Milestones in the History of Thought." At the 1996 gathering at Eastern Michigan University, he considered implications of five schools of thought for integrative inquiry in his presentation on "Interdisciplinary Domains and Complexity." At the Arizona State University-West conference in 1995, he participated in a panel on "Demands of Complexity on Integrative Communications." At the 1993 meeting hosted by Wayne State University, he defined "Criteria for Structural Thinking" that would help promote incorporation of structural thinking into interdisciplinary teaching and research. In 1990, at St. Anselm's in New Hampshire, his topic was "On Language Components of Integrative Studies." He proposed four terms for use in integrative sciences -- platform theory, domain theory, subsumption, and supersumption. In 1988, at the University of Texas-Arlington meeting, he explored how liberal arts could revitalize science. In his presentation on "Universal Priors to Science," he examined the roles of human beings, language, reasoning through relationships, and archival representation. In 1987, at Pennsylvania State University, he spoke on "Knowledge Integration and the Systems Community."

Prior to his passing, John was chosen to be editor of the new Transdisciplinary Journal of Engineering & Science, a project of the ATLAS organization. The journal will now be dedicated to honoring him by recognizing responsibilties for a culture of peace and transdisciplinary knowledge. He was also paid tribute in vault 217, the online newsletter of the Special Collections & Archives at the George Mason University Libraries. The tribute highlights selected portions of 100 archival boxes of professional materials he donated in 2000. Accessible online, the John N. Warfield Digital Collection includes his papers as well as oral history interviews, videos of class lectures, and filmed sessions of his Interactive Management process (http://digilib.gmu.edu:8080/xmlui/handle/1920/3059).

The second edition of John's book A Science of Generic Design, published by Iowa State University Press in 1994, is ample testimony to his accomplishments. It represents his thinking on managing complexity through systems design. Sitting next to my treasured copy of A Science of Generic Design is another collection of writings that tap the astonishing range of his mind, including essays on topics he presented at AIS conferences. In one of my personal favorites, "Reading for Bureaucrats," he offers an annotated digest of important readings culled from over thirty years of studying complexity. Other works pull together his own essays on complexity, and he lays out a plan for "The Great University" in The Wandweaver Solution. Characteristic of John, The Wandweaver Solution is a systematic proposal complete with research background, challenges, vision, programs, schedule and benefits. It was supported by a multi-year research support from the Ford Motor Company (http://www2.gmu.edu/ depts/t-iasis/wandwaver/wandw.htm).

In his last paper, published in this special issue, John Warfield exhibited another vital quality that defined his life. He never stopped working to achieve the kind of change he knew is needed. His plan for Horizons College acknowledges the importance of a liberal education and attendant values of critical thinking, analysis, and problem solving. Yet, he exhorted, a liberal education and the current structure of institutionalized learning are not enough to realize a science of synthesis and systems design grounded in the cognitive domain of complexity. The sweep of his intellect and experience is readily apparent in his vision, reaching from Aristotle, William Shakespeare, Alexander Pope to Ford Motor Company, the U.S. Defense Department, and the country of Ghana. Only a genuine "landscape of systems learning," he admonished, will be capable of the level of problematization and comprehensive portrayal, appropriate responses, and implementation and management of responsible programs that is required.

In this regard, John reminded me of another important figure who was one of the architects of the seminal 1972 book, Interdisciplinarity: Problems of Problems of Teaching and Research in Universities -- Leo Apostel. Even with their distinctively different intellectual backgrounds – one a philosopher and the other a systems engineer – and their different cultural styles – forged in American and European traditions -- they were both committed to bridging the discourses of interdisciplinarity and systems thinking. They also shared a tendency to stand still physically while talking, but their minds were also moving. And, they shared a rhetorical style, always interrogating underlying assumptions while formulating conceptual tools for interdisciplinarity and laying out an operational approach. When I met Leo, he talked about another visionary in the 1972 book -- Erich Jantsch. Unfortunately, Leo lamented, Jantsch died tragically too soon. It is all the more precious, then, that we had Leo, John, John's old friend Kenneth Boulding, and Joseph Kockelmans for so long. We learned much from them, cherish their friendship, and now carry on their work.

1 The Cognition Partition: Toward the Horizons College

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Abstract

The cognition partition is the name given to the division of learning into two domains: the domain of normality and the domain of complexity. Requirements for learing differ vastly between these two domains. The traditional division of learning is based on dividing by topical area, i.e., by discipline; but such a division is unsatisfactory because it implicitly embeds the assumption that there is no cognitive distinction to be made among the disciplines insofar as learning is concerned.

Examination of subject matter through the lens of the recent discovery of metrics of complexity makes very clear that many of the disciplines, and especially the social science disciplines, require reorganization for learning, based upon what has been learned about the cognitive aspects of complexity. This requires implementation of the cognition partition, using principles from systems science.

Implementation is best accomplished through a dedicated doctoral program in a new university appendage called the Horizons College, which is dedicated to systems design. This will accomplish desirable social objectives while expanding learning opportunities.

1.1 Introduction

There is an enculturated momentum to institutionalized learning. This momentum sustains long-established modes, applying them indiscriminately to subject matter. It is buttressed by mutually-supportive functional, topical, and temporal institutional structure. If attempts are made to break away along one axis, forces are activated along the other two to restore the system to its tight equilibrium.

Functional Structure by Organizational Chart. Virtually all universities are organized into colleges, schools, and departments, each zealously guarding its boundaries.

Topical Structure by Faculty. The departmental offerings are arranged into courses, and the individual faculty member zealously guards the proprietary courses.

Temporal Structure by Activity Sequence. Not only does this momentum apply to the continuing functional organization and minimal reorganization and to the arrangement of learning of subject matter; but it applies also to the sequencing of activity. So there is a parade of semester after semester, or quarter after quarter, commencement after commencement, with never a thought that there might be much to gain by a year of learning through interactive institutional redesign.

The Integrated Impact of the Multidimensional Institutional Structure. Taken together, this three-dimensional equilibrated space acts like a kind of educational Berlin Wall against which whatever forces of change may arise, encouraging them to falter and die.

"Physician, Heal Thyself". Ironically, the very institution whose structure resists macro-change magnificently is in the business of discovering the reasons why change in that institution is necessary. The same rule of personal advancement, known lovingly as "publish or perish", forces constant research and publication and re-examination of what has been done, with the inevitable statistical result that some small percentage of what is published turns out to be very revealing concerning the possibilities of improving both the learning environment and the quality of what is learned. Sooner or later some of what is learned can be aggregated into what amounts to a prescription for beneficial redesign of the institution itself.

The Irresolute Culture and the Tack-On: Industrial Parallels. There is something about cultural change that is independent of type of institution. In some respects, the university has its parallel in the large corporation. Two instances where large corporations have sought to introduce change that involved cultural issues come to mind. When IBM™ sought to enter the personal computer business, the company set up a separate entity with different rules, in order to avoid the bureaucracy which it felt was better suited to maintenance of ongoing business than to supporting innovation in a new enterprise. When General Motors sought to make a splash in the small car business, it set up a separate entity with different rules to produce the Saturn™, for the same reasons. When an organizational culture has evolved in such a way as to sustain itself against all kinds of external forces, yet finds that it is vital to accommodate to a new situation, it is vulnerable to change at the boundary by appending a new entity, with the thought that ultimately it can be absorbed into the larger organization. I will discuss the cognition partition in more detail and then describe the proposed addition to higher education that will offer the means of gradually overcoming the cultural momentum that presently defies all attempts to introduce the cognition partition into higher education.

1.2 Discovering the Two Domains

In recent years, evidence has been uncovered, both theoretical and empirical, mutually supportive, that a strong distinction must be made between the domain of normality and the domain of complexity. This distinction is cognitive in nature, having to do with the joint physiological, psychological, and sociological makeup of the human being. It cannot be understood by looking away from the human being. There is essentially nothing arguable about the distinction, as those who choose to look into the matter will discover; because the results are replicable. The distinction to be made is called the “cognition partition”, and it refers specifically to the act of dividing subject matter on the basis of complexity metrics. The two domains have been discovered by focusing upon one of them: the domain of complexity. The story of how this focusing came about has been told in historical detail (Warfield, 2003b). For full understanding of what is to follow, the reader will do well to read this history. Salient, and distinguishing, aspects of the domain of complexity are these:

- This domain is a cognitive domain.
- This domain hosts many problematic situations; i.e., situations that no one understands, butwhich are recognized as problematic by a group of interested individuals, at least some of whichhave partial understanding of the situation.
- When given the opportunity to do so, the group can describe the situation by writing numerousproblem statements (“component problems”) that are characteristic of the problematic situation.
- The viewpoints of the individuals with partial understanding as to the relative importance of the component problems are virtually uncorrelated this being described by the term “Spreadthink” (Warfield, 1995).
- The language used to describe the situation is invariably and obviously (to all) highly defective, and can only become suitably discursive after participation in well-facilitated group processes that are defined to enable linguistic enhancement (Warfield, 2004).
- When given the opportunity to do so, and given sufficient computer assistance in doing so, the group can structure the problematic situation in several valuable,mutually-supportive ways (Warfield, 2002).
- Structuring yields insight not possible in any other way.
- Structuring produces genuine consensus not achievable in any other way.
- Structuring produces logical consistency not achievable in any other way (Warfield, 2006).
- Structuring produces consensus designs not achievable in any other way.
- Structuring enables computation of a variety of metrics of complexity (Warfield, 2002, 2006).
- Evaluated metrics demonstrate unequivocally the presence of complexity, and enable interpretation of the requirement for the cognition partition by tying the values of the metrics to wellestablished and replicable empirical research from the behavioral sciences.
- Evaluated metrics of complexity enable alternative designs to be compared, which lend insights that facilitate making choices among competing system design concepts (Staley, 1995).

1.3 Complexity Metrics

A variety of metrics of complexity have been set forth in the literature. Dividing subject matter on the basis of these metrics will generally be facilitated by using several of them in conjunction. But to simplify the argument in the present paper, only one metric will be discussed: **The Aristotle Index** (Warfield, 2002). As might be suspected, since the subject of complexity is involved, its measurement involves some erudition. While the discussion has been given in great detail in the reference just cited, the essential assumptions will be given here. Aristotle's syllogism being a 3-statement format, imagine now that one could extend this syllogism format by interconnecting many syllogisms to form a syllogistic web of relationships. Suppose that what was being connected was a set of problem statements, all about some common situation, and that the syllogisms all expressed conditions about how these problems were mutually related. Now suppose that you could count the number of syllogisms that were interconnected in this web and divide the number by 10. To be specific, suppose you had 300 syllogisms interconnected, and then divided by 10.You would then have the number 30, **This number would be the Aristotle Index AI for the particular data given.**

As explained in detail in the references, the Aristotle Index value of 1 forms a border between the domain of normality and the domain of complexity. Any value of AI above 1 places the situation in the domain of complexity. In numerous situations encountered over the past few decades, the value of AI has always been well above 1.

This offers one reasonably good way to determine whether a topic to be learned lies in the domain of normality or the domain of complexity.

Also shown in the references are various other indexes of complexity which, taken together fully establish the requirement for the cognition partition.

1.4 Problem Orientation vs Situation Orientation

It is common in higher education and in many application fields to speak of "problem solving". In the domain of complexity, it is typical to find collections of interacting problems. This is why one typically finds networks of syllogisms when studying the interaction among problems; and why "problem-solving" is a cultural negative to be reserved for very late in the process when the cognition partition is involved. The word "situation" is highly useful to refer to a topic involving a collection of interacting problems.

Suppose, for example, a single university department chose to re-invent its discipline, having become convinced that its subject matter was appropriate for the cognition partition. How might it proceed?

One way to do so has been tested repeatedly over the past few decades. It begins with "problemization". I have described this (Warfield 2006) emphasizing Rabinow's summary of Foucault's work. When it is done, the department will see the problems that its faculty can think of, and clarification of the language in which these problems are described. Moreover, the faculty will have a "problematique", consisting of a portrait of how these problems are mutually related, by means of an "aggravation" relationship.

Computer Usage. the problematique, being a structure that involves numerous syllogisms in a tight logical pattern, cannot be reliably constructed without computer help. The computer program used to construct the problematique is called "Interpretive Structural Modeling" (Warfield, 1976). It is an interactive program, based in De Morgan's theory of relations (1847). It queries the group as to how one problem relates to another, waits for discussion and voting, and continues until the structural details are in hand, then computes the structural details. As an example, reported in 1976, when the faculty of the systems science department at the City University studied its own program, the faculty were quite surprised to learn something significant about their views that they had not known. They were research-oriented by nature, a finding of self-discovery, possible when systematic conversation takes place to structure a problematic situation that lies in the domain of complexity. A similar self-learning situation with relatively low values of metrics was reported by Roy Smith in working with the Redemptorists in England in a study of their church activities (Warfield, 2002). Deep conversation uncovers matters not found in ordinary discussion. Deep conversation uncovers relationships that are not found, unless sought at the level of detail which is characteristic of the problematique and the Aristotle Index.

Extending the Departmental Scope. It has often been said that higher education exists to educate students to think critically. Unfortunately, this education seems to have the effect of tending to immobilize society, since everyone can criticize and few seem to be able to venture into a design mode. In a design mode, one sometimes finds it necessary to choose the least undesirable from a set of undesirable possibilities. But if that cannot be done because of inability to act, a society may end up with the worst of all choices which is doing nothing while things deteriorate.

The same processes that are used in problemization can be used for design. Once the problemization is finished, options and optionatiques can be produced, again with computer help. Again, these processes are fully described in the literature. Metrics of complexity can be developed and different design possibilities can be compared for relative complexity.

1.5 Horizons College in System Design at the University Doctoral Level

Many executives who manage large corporations, or who occupy high level positions in national or state governments, have demonstrated repeatedly their incapability to cope with large-system emergencies. Yet those who act as spokespersons for higher education seem to be incapable of making any connection between such defective performances and the shortcomings of university education.

This connection should not be that difficult to make. Official higher-education documentation, consisting of goal statements and doctrine, not to say dogma, announces regularly that the primary goal of higher education, at least in the socalled "university college", and in the liberal arts, is to develop critical reasoning, the analytical ability of the students. No mention is made of synthesis or design. But critical reasoning assumes the pinnacle of significance when it is applied in a design mode. Is this too difficult to absorb?

Research on human behavior has demonstrated clearly severe physiologicalbehavioral limitations on the intellectual performance of human beings—limitations that are absent from the assumptions underlying the processes of higher education, with the predictable effect that graduates absorb and reflect these same defective assumptions in their professional and public lives (Warfield, 2002, 2006). The impact of these assumptions is highly visible in the gross mistakes that are made in conceiving and managing large public and private enterprises—mistakes that can be described as "incompetent system designs".

The Horizons College in System Design at the doctoral level in higher education is proposed as a corrective measure, to develop individuals who are capable of doing more than analyzing and criticizing. The graduates of such a program will be capable of developing comprehensive insights into situations of substantial complexity, portraying these situations comprehensively, designing appropriate responses to them, developing responsible programs for their resolution, and managing the implementation of these programs. This capability will arise through programmed collaborative activity, assisted with extensively-tested computer software that amplifies (without biasing) human cognitive attributes.

The organization and design of the Horizons College is not speculative. In effect, it has already been tested outside the university environment. A principal challenge is to the university community itself–a question as to whether this community can, on the one hand, absorb such an entity and provide the architectural surroundings that are essential for its activities and displays and, on the other hand, provide the intellectual prerequisites to the rising students who will enter this College from within the university.

1.6 Teaching Critical Thinking

Despite the pervasive impact on all human beings everywhere of large systems of all kinds, higher education has never accepted system design as a key part of its mission. To illustrate the situation, quoting from Dr. Stephen H. Balch[1] in his presentation to the Select Committee of the Pennsylvania House of Representatives on November 9, 2005:

> *"...it has long been the consensus of higher educators that the core mission of colleges and universities, apart from research, is education. This was made clear in the founding statement of the American Association of University Professors (AAUP) in 1915, and more recently in a landmark brief submitted to the Supreme Court by the American Council on Education (ACE) and fifty-three other academic associations, including the AAUP, in the 2003 case of Gratz vs. Bollinger, which stresses that the purpose of education is to instill the capacity for independent thought."*
>
> *"Educators believe that developing the powers of analysis in this way is not merely one among many skills to be taught; it is the chief skill, because on it rests understanding and freedom. Socrates thought knowledge and freedom so essential, and so dependent on close reasoning, that the unexamined life is not worth living. The purpose of education, held the Stoics who carried his idea forward, is to confront the passivity, challenging the student's mind to take charge of its own thought. To strengthen the ability to reason is to enable the student to determine what to believe, what to say, and what to do, rather than merely to parrot thoughts, words, and actions of convention, friends or family."*

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[1]Dr. Balch is President of the National Association of Scholars, 221 W itherspoon Street, 2 Floor, Princeton, New Jersey 08542-3215. The Association burst upon the educational scene with a report demonstrating a longitudinal study showing how standards in higher education had deteriorated over a period of several decades. Since then it has begun publishing a journal and a newsletter.

The context for this presentation was to try to impress upon the Pennsylvania House of Re resentatives the importance of trying to fight the growing tendency of faculty in higher education to take positions of advocacy on political matters, as opposed to carrying out the “core mission”, as outlined above. In offering Dr. Balch’ quotation, I must take it out of that context and put it in another context, that of noting how well it avoids completely the context of system design. Moreover, as I will describe, it presumes that the individual can cope with the complexity inherent in today’s society, merely as a consequence of experiencing degree programs in higher education—endowing higher education with a capability that it does not have. Educators must now begin to apply the very skills that they presume to develop in their graduates by asking themselves critically, and often, why their graduates have demonstrated in the public eye their lack of capability to cope with large system situations time after time. And if they do this often enough and with sufficient honesty, and in sufficient depth, perhaps what is proposed here will come to their studied attention.

1.7 Call to the Poets–First Call

> Hamlet: Thrift, thrift, Horatio! The funeral baked-meats did coldly furnish forth the marriage tables.
>
> Would I had met my dearest foe in heaven Or ever I had seen that day,
> Horatio! My father!- methinks
>
> I see my father.
>
> Horatio: O where, my lord?
>
> Hamlet: In my mind’s eye, Horatio.

So it is that Shakespeare speaks of the “mind’s eye”. And it is in the “mind’s eye” that I choose to speak of the human decision-making apparatus. For if a choice is to be made among several possibilities, the mind’s eye typically imagines these possibilities and decides on which will be chosen.

But it is the mind’s eye that is limited. As George A. Miller discovered (Miller, 1956), when the mind’s eye wishes to evoke items from memory, it is limited in immediate recall to the “magical number” seven plus or minus two. I have amplified this idea, showing that it can be limited to three plus or minus zero if the three interact (Warfield, 1988); for if there are four things and they interact, one has fifteen possibilities to be considered. Since I have discussed this in great detail elsewhere (Warfield, 2002), I won’t belabor it here.

The mind’s eye and the two eyes of the face have very different functions. The eyes of the face (please, allow me to call them the “feyes”, pronounced “fies”, since I have to speak of them endlessly) scan the external field of vision. The mind’s eye (please allow me to call it the “meye”, pronounced “my”, since I have to speak of it endlessly) can scan what is in the brain or it can see what the feyes provide it.

This distinctive two-fold capacity of the meye must be understood, in order to understand what is involved in learning to design systems. The magical number seven is involved when a politician responds to a TV pundit on the air, because the meye has access only to the internal field of vision. But the same individual might actually be involved in a constructive design activity if allowed to take part in an adventurous workshop in which the feyes were providing an external field of vision to supplement the work of the politician's meye. To make this effective, the surrounding architecture would be chosen to display the full landscape of the situation, as will be explained.

Ordinary Decisions. Imagine that you are driving down a busy highway looking for an unfamiliar cross street. With the feyes and the meye working in conjunction, the former supplying information from the external field of vision to the meye, you are successful in making the turn. But what if you had to drive with all the windows and the windshield painted black, with only a one-inch square aperture on the windshield to see through, and heavy traffic all around? And what if you have a load of passengers urging you to drive faster to reach the destination on time? Under these conditions the meye is totally stressed. Being unable to get any significant information from the feyes, it is forced to rely on the internal field of vision, or perhaps on what comes in gratuitously through the ear. Very likely there will be a crash. This situation is analogous to what decision makers are encountering when they attempt to cope with complexity while trying to rely on the meye without help from the feyes. Ordinary decisions, made over and over again, condition human behavior to a certain mode; and this conditioning does little or nothing to prepare the individual for working in the domain of complexity.

1.8 Call to the Poets–Second Call

Tis with our judgments as our watches, none

Go just alike, yet each believes his own.

Alexander Pope wrote these lines early in the 18 century at age twenty. These lines describe what we have discovered over and over again in work with groups involving complexity (Warfield, 1995), and which I titled "spreadthink". Each individual perceives different component problems of a situation to be the most important, no two people seeing situations comparably. ***Thus whoever holds the reins of the decision-maker is almost certainly going to make a decision based on an incorrect perspective. The proximate cause of this error is lack of insight into how the component problems in a problematic situation interact, and how this interaction fluidly changes as poorly-thought-out actions are taken.***

Higher Education Is Successful! If a goal of higher education is to get people to think differently, that goal is achieved to perfection in situations involving complexity. If a measure of success would be to find that, in situations involving complexity, no leader could find acquiescence in what is proposed, and find only criticism, that goal also has been achieved. I coined the word "spreadthink" to describe this situation, and explained how anyone who doubts the concept could readily reproduce the findings.

Surely it is not a goal of the denizens of higher education to immobilize society. On the contrary, one might hope that a goal is to find a way to make it possible to enhance life's experience.

In speaking to the Pennsylvania House, Dr. Balch was speaking against the high level of advocacy now found among faculty. Faculty are advocating social change blindly, lashing out, proposing "solutions" that will not work. What else would one expect from socially-sensitive people working in an organization that has bred and continues to breed, by choice, generations of critics? Is it to be expected that somehow a legislature can correct this condition, when the university itself has helped to create it e.g., by sensitizing whole generations to Karl Marx, but providing no constructive alternative?

Beyond Winston. Even Winston Churchill, who announced that democracy was not so great, but was just the best of what was available, might now be willing to suggest that even democracy could be improved if its practitioners could become more competent, and less inclined to flaunt their critical capacities, while demonstrating by their actions their constructive incompetence.

1.9 Systems Learning

Systems learning means to gain insight into the variety of problems that infect a situation, how these problems are interrelated, how they may be placed in categories for ease of reference, what options may be available for resolving the complexity that is inherent in a situation, and how the options may be interrelated in one or more proposed action strategies.

1.9.1 The Landscape of Systems Learning

The landscape of systems learning refers to a special field of vision, arrayed in such a way that the feyes can scan it over and over again, being commanded by meye, while meye, in turn, can, concurrently, draw on the internal field of vision when appropriate, all the while engaged in assimilating the insights required to expand on a comprehensive understanding of a situation that, initially, no one understood. Initially–that is—before a reasonably well-informed group of individuals engaged in a learning process to construct, with computer assistance, the components of the landscape of systems learning which, when arrayed in the external field of vision, provide the external supplement to meye that enables the kind of insight to be developed that no amount of typical university education can provide into a situation of substantial complexity.

The university education is very helpful. It simply is not sufficient, and can never be sufficient, in the absence of the structural components that are required to gain an understanding of the relationships among the components of the situation. This understanding will enable a truly deep and informed conversation to take place, which will eliminate the raucous, ill-informed, inevitable, unending, television nonsense that disgraces the living rooms of the nation today under the guise of "news" or "talk shows".

The "landscape of systems learning" means a large physical portrayal of four structures:

- the interrelationships among the component problems of a situation in the formof a problematique[2].
- the membership of the problems in categories in the form of a problems field
- the membership of the options in those same categories in the form of an options field.

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[2]*Warfield, J.N.(2002) , Understanding Complexity: Thought and Behavior, Palm Harbor, FL: AJAR Publishing Company. Numerous examples appear from a variety of applications.*

- and the interrelationship among options in the form of an option-atique, showingwhich options, if elected and carried out, will help achieve other options.

All four of these portrayals are to be laid out at human scale to enable walkingviewing conversations for the purposes of discussion, evaluation, learning, and possible amendment.

Little systems learning takes place now. What are the reasons for the absence of systems learning?

Omissions. On the one hand, one may speak of causes of omission: because of the absence of architecture to house the landscape, the failure of practitioners to learn what is required to construct the landscape, and a very limited capability to manage the processes involved in landscape construction.

Commissions. On the other hand, one may speak of ***causes of commission:***

- the accepted practices of developing glibness in verbal "problem-solving" ingrained by the educational system,
- the substitution of methods and theories for scientifically established practice,
- and the existence of many modestly-sized "paradigm villages" (they know who they are, and I will not identify them here, but I know who they are as well) whose "residents" enjoy social experiences, but do not necessarily go to pains to correlate their activities with the scientific method. Actually, they skip over science, like a child skips over a rope, when tripping over it, ignores it, and simply starts skipping all over again.

Impact of Paradigm Villages. Whatever benefits the paradigm villages may be producing, and they may (or may not) be producing many, they certainly dilute the possibilities for programs of the type described here if, for no other reasons, they confuse greatly both clients of education and educational administrators who, along with virtually all academic faculty, have no experience in system design and cannot make allocation decisions among many competing paradigm villages, each of which represents unique educational and social claims of merit.

1.9.2 Systems Science as the Base

The Horizons College will be founded in systems science . To make this feasible, a minimum set of resources[3] is essential. This set of resources can be inferred from

[3]*I have defined systems science in Warfield, J. N. (2006), An Introduction to Systems Science, Singapore: World Scientific. In this definition, systems science is a collection of nested sub-sciences. The least of these in the set theory sense is the sub-science of description. It is contained in a subscience of design, which is contained in a sub-science of complexity. The latter is contained in a sub-science of action, and the four of these make up the bulk of systems science. Only two methodologies are learned. If others are required, they bubble up as requirements from the application of systems science, and are imported from specific sciences. For more information, one may consult the Preface of that book.*

the description of the largest of the several subsets, known as Interactive Management, which is thoroughly described in the literature, and which has been practiced on several continents for more than two decades. There is no university which has adopted the entire panoply of requirements, but several have enabled enough activity to transpire to allow ample empirical evidence of efficacy and character to be set forth. This activity, along with recorded activity in various industrial and government settings, has furnished an ample set of scholarly resources for those who wish to dig deeply into the essence of this science, and to learn precisely what is involved in this science.

The Distinctive Foundations. While the distinctive foundations have been described elsewhere, it is appropriate to discuss them in more detail in this essay, since the Horizons College must be clearly distinguished from other parts of the university, in order to make its mission evident, not only to justify allocation of resources to this College, but also to help persuade other parts of the university to assist in educating those students who will eventually come to the Horizons College.

A good system designer must have an excellent background in a diversity of fields, and especially must have a kind of maturity that can only come from what is often called a "liberal education". Just as I have said, in effect, that a liberal education is inadequate to produce system designers, I now assert that system designers will be myopic if they have not had a liberal education or, its equivalent, in life experiences, if such exists.

Systems science is founded by taking into account collectively the following key bases:

- **Creativity.** The creative human being.
- **Fallibility.** The fallible human being, subject to various behavioral pathologies, especially those identified or illustrated by empirical behavioral discoveries in the last half of the 20 century, e.g., (Miller, 1956), (Allison, 1971), (Argyris, 1982), (Boulding, 1966), (Downs, 1966, 1994), (Janis, 1982), (Kapelouzos, 1989), (Lasswell, 1971), (March and Simon, 1958), (Miller, 1956), (Tuckman, 1965), (Warfield, 1995). Please see Warfield, 2006, Gallery in Appendix 1, for descriptions and pictures of most of these scholars.

- **Discursivity.** Discursivity that avoids linguistic pollution, roots out word bandits,emphasizes the avoidance of multiple meanings in the same context, and obliterates similar hobgoblins.
- **Computer Help With Logic.** Thought about thought, a legacy developing-painstakingly through more than two millennia, now made serviceable with thehelp of the modern digital computer, to structure the relationships among component problems and component options of difficult situations, thereby helping to develop the insights that cannot be gained by meye acting alone; enabling meye to gain the benefit of the field of vision that can be brought to bear, when the structural features of difficult situations can be tapped to supplement the associative and manipulative skills of meye which, otherwise, would be essentially helpless in the face of the complexity of the numerous situations that face leaders today.

Basing systems science in these foundations; and drawing on traditional academic subjects such as philosophy, logic, psychology, history, linguistics, computer science, and management, and remaining open to such other subjects as may be found to be relevant in the course of applied studies; one can hope to carve out for systems science a unique position in higher education. But for this to happen, the same principles and ideas that would be espoused in systems science should be applied to design the program that animates the Horizons College.

1.10 The Five-Point Horizons College Plan

The development of the Horizons College is not a simple project, and requires the coordinated achievement of a five-point plan, consisting of these major components:

- Faculty Development Program,
- Entering Student Development Program,
- Architecture Design and Construction Program,
- Internal Learning Program Design,
- External Project Program Design,

Each of these will be described, in turn.

1.10.1 Faculty Development Plan

To understand the requirements of the Faculty Development Plan, it may help to recite a developmental occurrence of a novel organization from the early 1970s. An agreement was signed between the governments of the United States and Korea. The two presidents agreed that Korea would send troops to help with the Viet Nam war, if the USA would provide researchers from the Battelle Memorial Institute to set up a research institute in Korea to help that country industrialize. I can recite this story authentically, because one of the key principals, Charles Peet, had an office next door to mine at Battelle, and was a key person in helping set up the Korean Institute of Science and Technology (KIST).

Charles Peet, an Unsung Designer. We had several conversations about this situation. Charles was very knowledgeable in chemistry, solid state physics, and investments. For years he had been advising a family investment group.

Charles told me that, upon hearing of the potential establishment of KIST, a flood of academics applied to go back to their home countries, leaving their academic positions in the USA and elsewhere. Most of these were rejected. Charles wanted hard-headed Korean citizens, (largely expatriates) people who understood the importance of creative designs, and of investing in what would provide economic benefits to a country. To the best of my knowledge he interviewed personally many of the early staff of KIST, and only chose those who did not see as the main goal of KIST to provide a place where academics could be comfortable, do their private research, write papers, and retire gracefully with a pension. Charles chose both staff and fields of future research for KIST.

Korea Becomes an Industrial Powerhouse. Some years later, as history records, Korea became an electronics powerhouse. Not only did it develop its electronics industry in competition with Japan, but was able to parlay that development into the automobile industry. Moreover, it was able to do contract research for other Asian countries, and to help establish in Korean universities research activities that would support the industrial development of the country. (When I went to Ghana as an adviser some years later, I advised the scientific establishment to hire the former President of KIST to come there and write a program for the scientific development of Ghana, which they did).

Faculty Selection. Since there is no established Horizons College, and no faculty with the kind of background needed for such a College, it is advisable to select and nurture the development of a faculty, much along the same philosophical lines as was applied in the development of KIST.

The most fundamental aim of the Horizons College is to fill a critical gap in higher education, i.e., to develop people who are competent in design of large systems in the face of complexity: problematic situations that no one understands. In such situations, the only way that progress can be made is to bring together people who have partial understanding, and to apply systems science to help them integrate what they know, then interpret their products as a service for them. In this way the insight is developed to design and implement ameliorative, corrective measures for the well-being of whatever organization or society is involved. This kind of task requires the most sensitive and competent individuals who, on the one hand, understand what it means to serve, and who, on the other hand, are not willing to tolerate the self-serving authoritarian personality of the know-it-all who does not understand what is required to make progress in an area of mass ignorance.

The saving grace in this is that there is a wide vista of educated people from whom to draw, and one can speculate that there is a sub-population who have been waiting for this type of opportunity. Since experience shows that such people have arisen (and there are a number of them identified in my 2006 book, coming from different locations around the globe), it should not be hard to suppose that a responsible recruiting effort will draw in a small core faculty which can be augmented later as required. Probably a single semester would suffice for this faculty to flesh out the other components of the Horizons College plan and to work out details as they arise.

1.10.2 Student Development Plan

Entering students must be chosen with the same or even greater care than the faculty. There is some, but not a great deal of experience to draw on with an entering student body for a demanding program of the type to be offered here. The principal challenge is one of connecting with other departments inside and outside the institution to assess potential students, to make the program known, and to locate possible sources of student support. The faculty will come first, and will have to produce the student development plan as one of their first collective tasks.

1.10.3 Architecture Design and Construction Program

One of the unique features of the Horizons College is the space required for the landscape displays.

Drawing on experience. The most direct source of experience on this lies in two individuals: Dr. Scott M. Staley of the Ford Motor Company, who has worked with architects to develop a plan for an architecture, and Dr. Henry Alberts, who has used space at the Defense Systems Management College over a five-year period, in which he worked with more than 300 defense program managers, carrying out the kind of work that would be done in the Horizons College.

1.10.4 Internal Program Design

The internal program design would largely involve three components.

Course selection, would be relatively easy, with many of the courses to be offered from other parts of the university, chosen to satisfy many of the aspects of systems science described earlier in this paper.

Faculty associate selection, would involve faculty from other parts of the university serving as associates, based upon their volunteer interests in the program of the Horizons College and, if desired, identifying projects for the next component.

Project selection, would involve projects being chosen from internal sources to assist parts of the university in organizing their curricula, or their strategic planning or to assist them in organizing their doctoral research programs, or administrative programs if desired. If there is little or no demand for such assistance (there has been demand in some institutions in England and Mexico), only internal teaching projects can be used in preparation for the conduct of external projects. These can be similar to student projects reported in the literature.

1.10.5 External Program Design

The external program design is the most important part of the program of the Horizons College, because it is in this program that the quality of the College will be tested. This program will involve working with outside organizations, public and private, identifying their problematic situations, and bringing their representatives to the College, where they will become actors in resolving their own situations with the assistance of the faculty of the College. This will involve the following component activities:

- Client selection
- Project definition
- Project selection
- Workshop management
- Report production
- Case study publication

The case study preparation will be the principal requirement for the doctoral degree in the Horizons College. Generally speaking, as the student proceeds toward the doctorate, the student will progress toward the capacity to carry out all of six steps in the external program, completing with the case study publication.

The Horizons College will provide case studies for a fee to other institutions, as a means of gradually inducing other institutions to establish Horizons Colleges, and as a way of supporting the graduate program of the College.

1.11 Examples: Highly-Varied Previous Designs

What has been designed to this point using the concepts discussed here? Many diverse designs have been created by a diversity of individuals, and they have been reported in a variety of places. I will mention a few diverse designs, details of which have been reported briefly in one or more of my books, where the curious reader can find more information than I give here. My purpose here is to emphasize the ubiquitous nature of the science, its applications, and its client population. These range from the design for the individual to the design for the giant bureaucracy and the giant corporation.

Portable Stereo. By a university sophomore: a portable stereo system specifying (features, type, overall weight, driver material, frequency response, voice coil leads, ear pad material, headband pressure, cord type, and earpiece options).

Student Escort Service. By a small group of university sophomores: a latenight student escort service listing: (publicity, staff, hours of weekend service, hours of weeknight service, lagtime, number of vehicles, scheduling, reasons for use, riders, means of prioritization of users, area covered, method of transportation, operational funding, and overhead funding).

National Legislation. By a group of more than 300 defense program managers, with a little help from the U. S. Congress: “The Acquisition Streamlining Act of 1994”.

Corporate-Wide Product Information Management System. By a group of engineers at one of the world’s largest corporations: a corporate wide product information management system.

Revolutionary Disarmament and Demobilization Plan. By a group of warlords and warriors in Liberia: a plan for disarmament and demobilization.

Foundation Food Distribution Plan. By a foundation: a plan for providing food assistance to a nation whose government had undergone a coup, which cut off an established mode of providing help.

Tribal Self-Governance Plan. By an Indian tribe: a plan for enhancing selfgovernance.

1.12 Summary and Conclusions

Institutions of higher education quite properly undertake to develop among students the ability to question received doctrine. Little or no comparable attention is given to the ability to synthesize on the scale of complexity that is encountered today in public and private organizations. Hence the critical talent is unaccompanied by an ability to convert the recognized deficiencies into constructive change in organizations and societies.

Consequently, there is perpetual discontent, angst which grows and takes on many negative forms in organizations and societies, sometimes accompanied by large-scale disasters that won't quit.

In response to this situation, a creative appendage to institutions of higher education is proposed, called a Horizons College, which will specialize in growing a talent of design at a high level among selected students who have already developed a broad perspective on the world, and who have sufficient insight and motivation to be in a position to benefit from and to carry into organizations an education that will equip them to take leadership roles.

The Horizons College will be based intellectually in systems science, and it will draw upon much of the existing resources of higher education. It will be built upon a five-point plan of development, and will take advantage of a history of successful description and application of systems science that has been carried out external to higher education.

The challenge now is to import this fledgling concept into higher education, to grow it there, and to let it become an integral part of higher education, where it will offer a new and vital leadership capability to institutions at a time when the complexity of society and its institutions threatens to overwhelm us all.

But in the interim period, existing academic programs may find it appropriate to begin to recognize the cognition partition in their programs, where appropriate.

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2 Methodology of Transdisciplinarity-Levels of Reality, Logic of the Included Middle and Complexity

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Abstract

The concept of levels of Reality, formulated in 1982, is the key concept of transdisciplinarity[1].

The introduction of the levels of Reality induces a multidimensional and multi-referential structure of Reality, signifying the coexistence between complex plurality and open unity. Every level is characterized by its incompleteness; the laws governing this level are just a part of the totality of laws governing all levels. And even the totality of laws does not exhaust the entire Reality; we have also to consider the interaction between Subject and Object. The zone between two different levels and beyond all levels is a zone of non-resistance to our experiences, representations, descriptions, images, and mathematical formulations. The Gödelian structure of levels of Reality implies the impossibility of a self-enclosed complete theory. Knowledge is forever open.

The unity of levels of Reality of the Object and its complementary zone of non-resistance defines the transdisciplinary Object. The unity of levels of Reality of the Subject and this complementary zone of non-resistance defines the transdisciplinary Subject. The zone of non-resistance plays the role of a third between the Subject and the Object, an interaction term which allows the unification of the transdisciplinary Subject

[1] *Apostel et al., 1972.*

and the transdisciplinary Object. This interaction term is called the Hidden Third. The ternary partition (Subject, Object, Hidden Third) is, of course, radically different from the binary partition (Subject vs. Object) of classical realism.

2.1 The War of Definations

2.1.1 How Transdisciplinarity was Born

Transdisciplinarity is a relatively young approach; Swiss philosopher and psychologist Jean Piaget (1896-1980) developed the concept seven centuries after disciplinarity had evolved.

The word itself first appeared in France, in 1970, in the talks of Jean Piaget, Erich Jantsch, and André Lichnerowicz at the international workshop "Interdisciplinarity– Teaching and Research Problems in Universities," organized by the Organization for Economic Co-operation and Development (OECD) in collaboration with the French Ministry of National Education and University of Nice[1].

In his contribution, Piaget gives the following description of transdisciplinarity: "Finally, we hope to see succeeding to the stage of interdisciplinary relations a superior stage, which should be 'transdisciplinary,' i.e. which will not be limited to recognize the interactions and/or reciprocities between the specialized researches, but which will locate these links inside a total system without stable boundaries between the disciplines."[2] While this description is vague, it has the merit of pointing to a new space of knowledge "without stable boundaries between the disciplines." However, the idea of a "total system" opens the trap of transforming transdisciplinarity into a super- or hyperdiscipline, a kind of "science of sciences." In other words, the description of Piaget leads to a closed system, in contradiction with his own requirement of the instability of boundaries between disciplines. The key point here is the fact that Piaget retained only the meanings "across" and "between" from the Latin prefix *trans*, eliminating the meaning "beyond." Understood in such a way, transdisciplinarity is just a new, "superior" stage of interdisciplinarity. I think Piaget was fully conscious of this alteration of transdisciplinarity, but the intellectual climate was not yet prepared for receiving the shock of contemplating the possibility of a space of knowledge *beyond* the disciplines. The proof is that in his introduction to the Proceedings of the workshop, Pierre Duguet honestly recognized that some experts wanted to see the word "transdisciplinarity" in the title of the workshop, but authorities of the OECD refused to do so because they were afraid to confuse some representatives of the member countries[3].

In his contributions, Erich Jantsch, an Austrian thinker living in California, falls in the trap of defining transdisciplinarity as a hyperdiscipline. He writes that transdisciplinarity is "the coordination of all disciplines and interdisciplines of the teaching system and the innovation on the basis of a general axiomatic approach."[4] He clearly situates transdisciplinarity in the disciplinary framework. However, the historical merit of Jantsch was to underscore the necessity of inventing an axiomatic approach for transdisciplinarity and also of introducing values in this field of knowledge.

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[2]*Piaget, 1972, p. 144.*

[3]*Duguet, 1972, p. 13.*

[4]*Jantsch, 1972 a, p. 108. The same ideas are expressed in Jantsch, 1972 b.*

Finally, the approach of André Lichnerowicz, a known French mathematician, is radically mathematical. He sees transdisciplinarity as a transversal play to describe "the homogeneity of the theoretical activity in different sciences and techniques, independently of the field where this activity is effectuated."[5] And, of course, this theoretical activity can be formulated, he thinks, only in mathematical language. Lichnerowicz writes: "The Being is put between parentheses, and it is precisely this non-ontological character which confers to mathematics its power, its fidelity, and its polyvalence."[6] The interest of Lichnerowicz for transdisciplinarity was accidental, but his remark about the non-ontological character of mathematics has to be remembered.

I described in some detail the three different positions of Piaget, Jantsch, and Lichnerowicz concerning transdisciplinarity because they can be found again, a quarter of a century later, in what I call "the war of definitions." The word "war" does not belong in the transdisciplinary vocabulary. However, I use it purposely because it appeared in the issue "Guerre et paix entre les sciences: disciplinarité et transdisciplinarité / War and Peace Between Sciences: Disciplinarity and Transdisciplinarity"[7] of a French magazine. In this issue, one of the authors asked for the interdiction of the word "transdisciplinarity."[7] His desire was obviously not satisfied.

I would like to add to this discussion about the incipient phase of transdisciplinarity the name of Edgar Morin. A short time after the Nice meeting, Morin begins to use the word "transdisciplinarity," and he even leads a transdisciplinary laboratory in human sciences within the framework of a prestigious French research institution. It is true that Morin did not give a definition of transdisciplinarity. For him, transdisciplinarity was, in that period, a kind of messenger of the freedom of thinking, a go-between discipline.

2.1.2 Beyond Disciplines

I proposed the inclusion of the meaning "beyond disciplines" in 1985[8] and have since developed this idea over the years in articles, books, and various official international documents. Many other researchers over the world contributed to this development of transdisciplinarity. A key date in this development is 1994, when the Charter of Transdisciplinarity[9] was adopted by the participants at the First World Congress of Transdisciplinarity (Convento da Arrábida, Portugal).

This idea did not come from heaven or just from the pleasure of respecting the etymology of the word trans but from my long practice of quantum physics. For an outsider, it might seem paradoxical that it is from the very core of exact sciences that we arrive at the idea of limits of disciplinary knowledge. But from within, it provides evidence of the fact that, after a very long period, disciplinary knowledge has reached its own limitations with far-reaching consequences not only for science but also for culture and social life.

The crucial point here is the status of the Subject.

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[5] *Lichnerowicz, 1972, pp. 130-131.*
[6] *Ibid., pp. 127.*
[7] *Alain Caillé, in "Guerre,", 1996.*
[8] *Nicolescu, 1985.*
[9] *"Charter."*

Modern science was born through a violent break with the ancient vision of the world. It was founded on the idea—surprising and revolutionary for that era—of a total separation between the knowing subject and Reality, which was assumed to be completely independent from the subject who observed it. This break allowed science to develop independently of theology, philosophy, and culture. It was a positive act of freedom. But today, the extreme consequences of this break, incarnated by the ideology of scientism, pose the potential danger of self-destruction of our species.

On the spiritual level, the consequences of scientism have been considerable: the only knowledge worthy of its name must therefore be scientific, objective; the only reality worthy of this name must be, of course, objective reality, ruled by objective laws. All knowledge other than scientific knowledge is thus cast into the inferno of subjectivity, tolerated at most as a meaningless embellishment or rejected with contempt as a fantasy, an illusion, a regression, or a product of the imagination. Even the word "spirituality" has become suspect and its use has been practically abandoned.

Objectivity, set up as the supreme criterion of Truth, has one inevitable consequence: the transformation of the Subject into an Object. The death of the Subject is the price we pay for objective knowledge. The human being became an object—an object of the exploitation of man by man; an object of the experiments of ideologies that are proclaimed scientific; an object of scientific studies to be dissected, formalized, and manipulated. The Man–God has become a Man–Object, of which the only result can be self-destruction. The two world massacres of this century, not to mention the multiple local wars and terrorism, are only the prelude to self-destruction on a global scale.

In fact, with very few exceptions—Husserl, Heidegger, Gadamer, or Cassirer, for example—modern and post-modern thinkers gradually transformed the Subject in a grammatical subject. The Subject is today just a word in a phrase[10].

The quantum revolution radically changed this situation. The new scientific and philosophical notions it introduced—the principle of superposition of quantum "yes" and "no" states, discontinuity, non-separability, global causality, quantum indeterminism—necessarily led the founders of quantum mechanics to rethink the problem of the complete Object/Subject separation. For example, Werner Heisenberg, Nobel Prize winner of Physics, thought that one must suppress any rigid distinction between the Subject and Object, between objective reality and subjective reality. "The concept of 'objective' and 'subjective,'" writes Heisenberg, "designate[s…] two different aspects of one reality; however we would make a very crude simplification if we want to divide the world in[to] one objective reality and one subjective reality. Many rigidities of the philosophy of the last centuries are born by this black and white view of the world."[11] Heisenberg also asserts that we have to renounce the privileged reference to the exteriority of the material world. "The too strong insistence on the difference between scientific knowledge and artistic knowledge comes from the wrong idea that concepts describe perfectly the 'real things.' […] All true philosophy is situated on the threshold between science and poetry."[12]

My line of thinking is in perfect agreement with that of Heisenberg. For me, "be-

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[10]*Descombes, 2004.*

[11]*Heisenberg, 1998, p. 269.*

[12]*Idem, pp. 363-364.*

yond disciplines" precisely signifies the Subject, and, more precisely, the Subject-Object interaction. The transcendence inherent in transdisciplinarity is the transcendence of the Subject. The Subject cannot be captured in a disciplinary camp.

The meaning "beyond disciplines" leads us to an immense space of new knowledge. The main outcome was the formulation of the methodology of transdisciplinarity, which I will analyze in the next section. It allows us also to clearly distinguish between multidisciplinarity, interdisciplinarity, and transdisciplinarity.

Multidisciplinarity concerns itself with studying a research topic in not just one discipline but in several simultanously. From this perspective, any topic will ultimately be enriched by incorporating the perspectives of several disciplines. Multidisciplinarity brings a plus to the discipline in question, but this "plus" is always in the exclusive service of the home discipline. In other words, the multidisciplinary approach overflows disciplinary boundaries while its goal remains limited to the framework of disciplinary research.

Interdisciplinarity has a different goal than multidisciplinarity. It concerns the transfer of methods from one discipline to another. Like multidisciplinarity, interdisciplinarity overflows the disciplines, but its goal still remains within the framework of disciplinary research. Interdisciplinarity even has the capacity of generating new disciplines, such as quantum cosmology and chaos theory.

Transdisciplinarity concerns that which is at once between the disciplines, across the different disciplines, and beyond all disciplines. Its goal is the understanding of the present world, of which one of the imperatives is the unity of knowledge[13].

As one can see, there is no opposition between disciplinarity (including multidisciplinarity and interdisciplinarity) and transdisciplinarity, but there is instead a fertile complementarity. In fact, there is no transdisciplinarity without disciplinarity. In spite of this fact, the above considerations provoked, around 1990, a more or less violent war of definitions. This war is not yet finished.

There is a specific different approach of transdisciplinarity that is characterized by the refusal of formulating any methodology and by its exclusive concentration on joint problem-solving of problems pertaining to the science-technology-society triad. This approach is represented by figures like Michael Gibbons[14] and Helga Nowotny[15]. The point of view of this transdisciplinary current was largely expressed at the Zürich Congress, held in the year 2000[16].

This version of transdisciplinarity does not exclude the meaning "beyond disciplines" but reduces it to the interaction of disciplines with social constraints. The social field necessarily introduces a dimension "beyond disciplines," but the individual human being is conceived of as part of a social system only. The spiritual dimension is therefore absent in this approach.

It is difficult for us to understand why "joint problem solving" must be the unique aim of transdisciplinarity. It is certainly one of the important aims but not the only aim. The use of such a narrow characterization seems to us dangerous, as in religion, allow-

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[13] *Nicolescu, 1996.*

[14] *Gibbons, 1994.*

[15] *Nowotny, 1994 and "The Potential of Transdisciplinarity".*

[16] *Thompson Klein et al., 2001.*

ing unnecessary wars and unproductive dogmatism. Is transdisciplinarity concerning only society as a uniform whole, or, the human being who is (or has to be) in the center of any civilized society? Are we allowed to identify *knowledge* with *production of knowledge*? Why does the potential of transdisciplinarity have to be reduced to produce "better science"? Why does transdisciplinarity have to be reduced to "hard science"? In other words, the Subject-Object interaction seems to us to be at the very core of transdisciplinarity and not the Object alone.

I think the unconscious barrier to a true dialogue comes from the inability of certain transdisciplinary researchers to think about discontinuity. I will give an image in order to express what I have in mind. For them, the boundaries between disciplines are like boundaries between countries, continents, and oceans on the surface of the Earth. These boundaries are fluctuating in time, but a fact remains unchanged: the continuity between territories. We have a different approach of the boundaries between disciplines. For us, they are like the separation between galaxies, solar systems, stars, and planets. It is the movement itself that generates the fluctuation of boundaries. This does not mean that a galaxy intersects another galaxy. When we cross the boundaries, we meet the interplanetary and intergalactic vacuum. This vacuum is far from being empty; it is full of invisible matter and energy. It introduces a clear discontinuity between territories of galaxies, solar systems, stars, and planets. Without the interplanetary and intergalactic vacuum, there is no Universe.

It is my deep conviction that our formulation of transdisciplinarity is both unified (in the sense of unification of different transdisciplinary approaches) and diverse: unity in diversity and diversity through unity is inherent to transdisciplinarity. Much confusion arises by failing to recognize that there is a *theoretical transdisciplinarity*, a *phenomenological transdisciplinarity*, and an *experimental transdisciplinarity.*

The word theory implies a general definition of transdisciplinarity and a well-defined methodology (which has to be distinguished from "methods"; a single methodology corresponds to a great number of different methods). The word phenomenology implies building models that connect the theoretical principles with the already observed experimental data in order to predict further results. The word experimental implies performing experiments following a well-defined procedure, allowing any researcher to get the same results when performing the same experiments.

I classify the work done by Michael Gibbons and Helga Nowotny as phenomenological transdisciplinarity, while I define my own work[17], as well as that of Jean Piaget and Edgar Morin[18], as theoretical transdisciplinarity. In its turn, experimental transdisciplinarity concerns a large number of experimental data already collected not only in the framework of knowledge production but also in fields such as education, psychoanalysis, the treatment of pain in terminal diseases, drug addiction, art, literature, history of religions, etc. The reduction of transdisciplinarity to only one of its aspects is very dangerous because it will transform transdisciplinarity into a temporary fashion, which I predict will disappear soon just as many other fashions in the field of culture and knowledge have indeed vanished. The huge potential of transdisciplinarity will never

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[17]*Nicolescu, 1985, 1986, 1991, 1996, 1998, 2000, 2002, 2004-2009.*

[18]*Morin, 1999.*

be accomplished if we do not accept the simultaneous and rigorous consideration of the three aspects of transdisciplinarity. This simultaneous consideration of theoretical, phenomenological, and experimental transdisciplinarity will allow both a unified and non-dogmatic treatment of the transdisciplinary theory and practice, coexisting with a plurality of transdisciplinary models. ATLAS seems to me an ideal place to practice all three aspects of transdisciplinarity in a fruitful manner.

2.2 Formulation of the methodology of Transdisciplinarity

2.2.1. The Axiomatic Character of the Methodology of Transdisciplinarity

The most important achievement of transdisciplinarity in present times is, of course, the formulation of the methodology of transdisciplinarity, accepted and applied by an important number of researchers in many countries around the world. In the absence of a methodology, transdisciplinarity would be just talking, an empty discourse and therefore a short-term living fashion.

The axiomatic character of the methodology of transdisciplinarity is an important aspect. This means that we have to limit the number of axioms (or principles or pillars) to a minimum number. Any axiom that can be derived from the already postulated ones would have to be rejected.

This fact is not new. It already happened when disciplinary knowledge acquired its scientific character due the three axioms formulated by Galileo Galilei in Dialogue on the Great World Systems[19]:

1. *There are universal laws, of a mathematical character.*
2. *These laws can be discovered by scientific experiment.*
3. *Such experiments can be perfectly replicated.*

It should be obvious that if we try to build a mathematical bridge between science and ontology, we will necessarily fail. Galileo himself makes the distinction between human mathematics and divine mathematics[20]. Human mathematics constitutes, he says (via Salvati), the common language of human beings and God, while divine mathematics is connected with the direct perception of the totality of all existing laws and phenomena. Transdisciplinarity tries to seriously take this distinction into account. A bridge can be built between science and ontology only by taking into account the totality of human knowledge. This requires a symbolic language, different from mathematical language and enriched by specific new notions. Mathematics is able to describe repetition of facts due to scientific laws, but transdisciplinarity is about the singularity of the human being and human life. The key point here is, once again, the irreducible presence of the Subject, which explains why transdisciplinarity cannot be described by a mathematical formalism. The dream of the mathematical formalization of transdisciplinarity is just a phantasm, the phantasm induced by centuries of disciplinary knowledge.

After many years of research, we have arrived[21] at the following three axioms of the methodology of transdisciplinarity:

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[19]*Galileo, 1956, 1992.*

[20]*Galileo, 1992, p. 192.*

1. **The ontological axiom**: *There are, in Nature and society and in our knowledge of Nature and society, different levels of Reality of the Object and, correspondingly, different levels of Reality of the Subject.*
2. **The logical axiom**: *The passage from one level of Reality to another is ensured by the logic of the included middle.*
3. **The complexity axiom**: *The structure of the totality of levels of Reality or perception is a complex structure: every level is what it is because all the levels exist at the same time.*

The first two get their experimental evidence from quantum physics, but they go well beyond exact sciences. The last one has its source not only in quantum physics but also in a variety of other exact and human sciences. All three are in agreement with traditional thinking present on the earth since the beginning of historical times.

Axioms cannot be demonstrated; they are not theorems. They have their roots in experimental data and theoretical approaches, and their validity is judged by the results of their applications. If the results are in contradiction with experimental facts, they have to be modified or replaced.

Let me note that, in spite of an almost infinite diversity of methods, theories, and models that run throughout the history of different scientific disciplines, the three methodological postulates of modern science have remained unchanged from Galileo. Let us hope that the same will prove to be true for transdisciplinarity and that a large number of transdisciplinary methods, theories, and models will appear in the future.

Let me also note that only one science has entirely and integrally satisfied the three Galilean postulates: physics. The other scientific disciplines only partially satisfy the three methodological postulates of modern science. However, the absence of rigorous mathematical formulation in psychology, psychoanalysis, history of religions, law theory, and a multitude of other disciplines did not lead to the elimination of these disciplines from the field of science. At least for the moment, not even an exact science like molecular biology can claim a mathematical formulation as rigorous as that of physics. In other words, there are *degrees of disciplinarity* which can more or less completely take into account the three methodological postulates of modern science. Likewise, the process of more or less taking completely into account the three methodological pillars of transdisciplinary research will generate different degrees of transdisciplinarity. Large avenues are open for a rich and diverse transdisciplinary research.

The above three axioms give a precise and *rigorous definition of transdisciplinarity.* This definition is in agreement with the one sketched by Jean Piaget.

Let me now describe the essentials of these three transdisciplinary axioms.

2.2.2. The Ontological Axiom: Levels of Reality and Levels of Perception

The key concept of the transdisciplinary approach to Nature and knowledge is the concept of *levels of Reality.*

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[21]*Nicolescu, 1996.*

Here, the meaning we give to the word "Reality" is pragmatic and ontological at the same time.

By "Reality," we intend first of all to designate that which *resists* our experiences, representations, descriptions, images, or even mathematical formulations.

Insofar as Nature participates in the being of the world, one has to assign also an ontological dimension to the concept of Reality. Reality is not merely a social construction, the consensus of a collectivity, or some inter-subjective agreement. It also has a trans-subjective dimension; for example, experimental data can ruin the most beautiful scientific theory.

Of course, one has to distinguish the words "Real" and "Reality." *Real* designates that which is, while Reality is connected to resistance in our human experience. The "Real" is, by definition, veiled forever, while "Reality" is accessible to our knowledge.

By "level of Reality," I designate a set of systems that are invariant under certain laws. For example, quantum entities are subordinate to quantum laws, which depart radically from the laws of the macrophysical world. That is to say that two levels of Reality are different if, while passing from one to the other, there is a break in the applicable laws and a break in fundamental concepts (like, for example, causality). Therefore there is a *discontinuity* in the structure of levels of Reality, similar to the discontinuity reigning over the quantum world.

Every level of Reality has its associated space-time, different from one level to the other. For example, the classical realism is associated with the 4-dimensional space-time (three dimensions of space and one dimension of time), while the quantum realism is associated with a space-time whose number of dimensions is greater than four. The introduction of the levels of Reality induces a multidimensional and multireferential structure of Reality.

A new Principle of Relativity[22] emerges from the coexistence between complex plurality and open unity in our approach: *no level of Reality constitutes a privileged place from which one is able to understand all the other levels of Reality.* A level of Reality is what it is because all the other levels exist at the same time. This Principle of Relativity is what originates a new perspective on religion, politics, art, education, and social life. And when our perspective on the world changes, the world changes. The great Brazilian educator Paulo Freire asserts in his *Pedagogy of the Oppressed*[23] that saying a true word is equivalent to the transformation of the world.

In other words, our approach is not hierarchical. There is no fundamental level. But its absence does not mean an anarchical dynamic but a coherent one of all levels of Reality, both those already discovered and those that will be discovered in the future.

Every level is characterized by its *incompleteness:* the laws governing this level are just a part of the totality of laws governing all levels. And even the totality of laws does not exhaust the entire Reality; we have also to consider the Subject and its interaction with the Object.

The zone between two different levels and beyond all levels is a zone of non-resistance to our experiences, representations, descriptions, images, and mathematical formulations. Quite simply, the transparence of this zone is due to the limitations of our

[22] *Nicolescu, 1996, pp. 54-55.*
[23] *Freire, 1968.*

bodies and of our sense organs—limitations that apply regardless of what measuring tools are used to extend these sense organs. We therefore have to conclude that the topological distance between levels is finite. However, this finite distance does not mean a finite knowledge. Take a segment of a straight line—it contains an infinite number of points. In a similar manner, a finite topological distance could contain an infinite number of levels of Reality. We have work to do till the end of time.

This open structure of the unity of levels of Reality is in accord with one of the most important scientific results of the twentieth century concerning arithmetic, the theorem of Kurt Gödel, which states that a sufficiently rich system of axioms inevitably leads to results that are either undecidable or contradictory. The implications of Gödel's[24] theorem have considerable importance for all modern theories of knowledge, primarily because it concerns not just the field of arithmetic but all of mathematics that include arithmetic. The Gödelian structure of levels of Reality implies the impossibility of a self-enclosed, complete theory. Knowledge is forever open.

The zone of non-resistance corresponds to the sacred—to that which does not submit to any rationalization. Proclaiming that there is a single level of Reality eliminates the sacred, and self-destruction is generated.

The unity of levels of Reality and its complementary zone of non-resistance constitutes what we call the transdisciplinary Object.

Inspired by the phenomenology of Edmund Husserl[25], I assert that the different levels of Reality of the Object are accessible to our knowledge thanks to the different levels of Reality of the Subject. They permit an increasingly general, unifying, encompassing vision of Reality without ever entirely exhausting it.

As in the case of levels of Reality of the Object, the coherence of levels of Reality of the Subject presupposes a zone of non-resistance to perception.

The unity of levels of Reality of the Subject and this complementary zone of non-resistance constitutes what we call the transdisciplinary Subject.

The two zones of non-resistance of transdisciplinary Object and Subject must be identical for the transdisciplinary Subject to communicate with the transdisciplinary Object. A flow of consciousness that coherently cuts across different levels of perception must correspond to the flow of information coherently cutting across different levels of Reality. The two flows are interrelated because they share the same zone of non-resistance.

Knowledge is neither exterior nor interior; it is simultaneously exterior and interior. The studies of the universe and of the human being sustain one another. Without spirituality, the knowledge is a dead knowledge.

The zone of non-resistance plays the role of a third between the Subject and the Object, an Interaction term, which acts like a secretly included middle that allows for the unification of the transdisciplinary Subject and the transdisciplinary Object while preserving their difference. I will call this Interaction term the Hidden Third.

Our ternary partition (Subject, Object, Hidden Third) is, of course, different from the binary partition (Subject vs. Object) of classical realism.

The emergence of at least three different levels of Reality in the study of natural

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[24] *Nagel and Newman, 1958.*

[25] *Husserl, 1966.*

systems—the macrophysical level, the microphysical level, and the cyber-space-time (to which one might add a fourth level, that of superstrings, unifying all physical interactions)—is a major event in the history of knowledge.

Based upon our definition of levels of Reality, we can identify other levels than just the ones in natural systems. For example, in social systems, we can speak about the individual level, the geographical and historical community level (family, nation), the cyber-space-time community level, and the planetary level.

Levels of Reality are radically different from levels of organization as these have been defined in systemic approaches[26]. Levels of organization do not presuppose a discontinuity in the fundamental concepts; several levels of organization can appear at the same level of Reality. The levels of organization correspond to different structures of the same fundamental laws.

The levels of Reality and the levels of organization offer the possibility of a new taxonomy of the more than 8000 academic disciplines existing today. Many disciplines coexist at the same level of Reality even if they correspond to different levels of organization. For example, Marxist economy and classical physics belong to one level of Reality, while quantum physics and psychoanalysis belong to another level of Reality.

The existence of different levels of Reality has been affirmed by different traditions and civilizations, but this affirmation was founded either on religious dogma or on the exploration of the interior universe only.

The transdisciplinary Object and its levels of Reality, the transdisciplinary Subject and its levels of perception, and the Hidden Third define the transdisciplinary model of Reality. Based on this ternary structure of Reality, we can deduce other ternaries of levels that are extremely useful in the analysis of concrete situations by contextualization:

Levels of organization – Levels of structuring – Levels of integration
Levels of confusion – Levels of language – Levels of interpretation
Physical levels – Biological levels – Psychical levels
Levels of ignorance – Levels of intelligence – Levels of contemplation
Levels of objectivity – Levels of subjectivity – Levels of complexity
Levels of knowledge – Levels of understanding – Levels of being
Levels of materiality – Levels of spirituality – Levels of non-duality

I formulated the idea of levels of Reality in 1976 during a post-doctoral stay at the Lawrence Berkeley Laboratory following stimulating discussions with Geoffrey Chew, the founder of the bootstrap theory, and other colleagues. My main motivation was the fact that this idea offered a logical solution to the incompatibility between the theory of relativity and quantum mechanics. I interpreted this incompatibility as the necessity of enlarging the field of Reality by abandoning the classical idea of a single level of Reality.

In 1981, I was intrigued by the idea of a veiled reality of Bernard d'Espagnat[27], but I realized that his solution was not satisfactory, and I therefore decided to publish my findings in an article published in 1982[28] and later, in an elaborated form, in 1985, in the first edition of my book We, the particle and the world[29].

In 1998, I was surprised to discover the idea of levels of Reality expressed in a different form, in a book by Werner Heisenberg, Philosophy - The manuscript of 1942.

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[26] *Camus et al., 1998.*

This book had a quite astonishing history: it was written in 1942[30], but it was published in German-only in 1984. I read the French translation of the book in 1998.

The philosophy of Heisenberg is based on two main ideas: the first is the notion of levels of Reality corresponding to different modes of embodying objectivity in terms of the respective process of knowledge, and the second is the gradual erasing of the familiar concept of 3-dimensional space and 1-dimensional time.

For Heisenberg, reality is "the continuous fluctuation of the experience as captured by consciousness. In that sense, it can never be identified to a closed system."[31] By "experience," he understands not only scientific experiments but also the perception of the movement of the soul or of the autonomous truth of symbols. For him, reality is a tissue of connections and of infinite abundance without any ultimate founding ground.

"One can never reach an exact and complete portrait of reality,"[32] writes Heisenberg.

The incompleteness of physical laws is therefore present in his philosophy, even if he makes no explicit reference to Gödel.

Heisenberg asserts many times, in agreement with Husserl, Heidegger, and Cassirer (whom he knew personally), that one has to suppress any rigid distinction between the Subject and Object. He also writes that one has to renounce the privileged reference to the exteriority of the material world and that the only way to understand the nature of reality is to accept its division in regions and levels.

The similarity to my own definition of reality is striking, but the differences are also important.

By "region of reality," Heisenberg understands a region characterized by a specific group of relations. His regions of reality are, in fact, strictly equivalent to the levels of organization of contemporary systemic thinking.

His motivation for distinguishing regions and levels of reality is identical to my own motivation: the break between classical and quantum mechanics.

Heisenberg classifies the numerous regions of reality in only three levels, in terms of the different proximity between the Object and the Subject[33]. He deduces that the rigid distinction between exact and human sciences has to be abandoned, a fact which sounds very, very transdisciplinary.

Heisenberg's first level of reality corresponds to fields that embody objectivity in an independent way from the knowledge process. Classical physics, electromagnetism, and the two theories of relativity of Einstein belong in this level.

The second level corresponds to fields inseparable from the knowledge process: quantum mechanics, biology, and the sciences of consciousness (like psychoanalysis), for example.

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[27]*d'Espagnat, 1981.*

[28]*Nicolescu, 1982, pp. 68-77.*

[29]*Nicolescu, 1985.*

[30]*Heisenberg, 1998.*

[31]*Idem., p. 166.*

[32]*Ibid., p. 258.*

[33]*bid., p. 372*

Finally, the third level corresponds to fields created in connection with the knowledge process. He situates there philosophy, art, politics, the metaphors concerning God, the religious experience, and the artistic creative experience.

If the first two levels of Heisenberg totally correspond to my own definition, the third one mixes levels and non-levels (in other words, the zones of non-resistance). The religious experience and the artistic creative experience cannot be assimilated to levels of Reality. They merely correspond to crossing levels in the zone of non-resistance. The absence of resistance and especially the absence of discontinuity in the philosophy of Heisenberg explain the difference between his approach and mine. A rigorous classification of regions in levels cannot be obtained in the absence of discontinuity.

Heisenberg insists on the crucial role of intuition: "Only an intuitive thinking," writes Heisenberg, "could bridge the abyss between old and new concepts; the formal deduction is impotent in realizing this bridge [...][34]" But Heisenberg did not draw the logical conclusion concerning this impotence of formal thinking; only the non-resistance to our experiences, representations, descriptions, images, or mathematical formalisms can bridge the abyss between two levels. This non-resistance restores the continuity broken by levels.

2.2.3 The Logical Axiom: The Included Middle

The incompleteness of the general laws governing a given level of Reality signifies that, at a given moment of time, one necessarily discovers contradictions in the theory describing the respective level: one has to assert A and non-A at the same time. This Gödelian feature of the transdisciplinary model of Reality is verified by all the history of science: a theory leads to contradictions and one has to invent a new theory solving these contradictions. It is precisely the way in which we went from classical physics to quantum physics.

However, our habits of mind, scientific or not, are still governed by the classical logic, which does not tolerate contradictions. The classical logic is founded on three axioms:

1. The axiom of identity: A is A.
2. The axiom of non-contradiction: A is not non-A.
3. The axiom of the excluded middle: There exists no third term T ("T" from "third") which is at the same time A and non-A.

Knowledge of the coexistence of the quantum world and the macrophysical world and the development of quantum physics have led, on the level of theory and scientific experiment, to pairs of mutually exclusive contradictories (A and non-A): wave and corpuscle, continuity and discontinuity, separability and non-separability, local causality and global causality, symmetry and breaking of symmetry, reversibility and irreversibility of time, and so forth.

The intellectual scandal provoked by quantum mechanics precisely consists in the fact that the pairs of contradictories that it generates are actually mutually exclusive when they are analyzed through the interpretive filter of classical logic.

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[34]*Idem, p. 261.*

However, the solution is relatively simple: one has to abandon the third axiom of the classical logic, imposing the exclusion of the third, the included middle T.

History will credit Stéphane Lupasco (1900-1988)[35] with having shown that the logic of the included middle is a true logic, mathematically formalized, multivalent (with three values: A, non-A, and T) and non-contradictory[36].

In fact, the logic of the included middle is the very heart of quantum mechanics: it allows us to understand the basic principle of the superposition of "yes" and "no" quantum states.

Heisenberg was fully conscious of the necessity of adopting the logic of the included middle. "There is – writes Heisenberg – a fundamental principle of classical logic which seems to need to be modified: in classical logic, if one assertion has a meaning, one supposes that either this assertion or its negation has to be true. Only one of the sentences "There is a table here" and "There is no table here" is true: tertium non datur, i.e. there is not a third possibility and this is the principle of the excluded middle. [...] In quantum theory, one has to modify this law of the excluded middle. If one protests again any modification of this basic principle, one can immediately argue that this principle is implicated in the ordinary language [...]. Consequently, the description in ordinary language of a logical reasoning which does not apply to this language would mean simply a self-contradiction."[37]

Our understanding of the axiom of the included middle — there exists a third term T which is at the same time A and non-A — is completely clarified once the notion of "levels of Reality", not existing in the works of Lupasco, is introduced.

In order to obtain a clear image of the meaning of the included middle, let us represent the three terms of the new logic — A, non-A, and T — and the dynamics associated with them by a triangle in which one of the vertices is situated at one level of Reality and the two other vertices at another level of Reality. The included middle is in fact an included third. If one remains at a single level of Reality, all manifestation appears as a struggle between two contradictory elements. The third dynamic, that of the T-state, is exercised at another level of Reality, where that which appears to be disunited is in fact united, and that which appears contradictory is perceived as non-contradictory.

It is the projection of the T-state onto the same single level of Reality which produces the appearance of mutually exclusive, antagonistic pairs (A and non-A). A single level of Reality can only create antagonistic oppositions. It is inherently self-destructive if it is completely separated from all the other levels of Reality. A third term which is situated at the same level of Reality as that of the opposites A and non-A, cannot accomplish their reconciliation. Of course, this conciliation is only temporary. We necessarily discover contradictions in the theory of the new level when this theory confronts new experimental facts. In other words, the action of the logic of the included middle on the different levels of Reality induces an open structure of the unity of levels of Reality. This structure has considerable consequences for the theory of knowledge because it implies

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[35] *Badescu and Nicolescu (ed.), 1999.*

[36] *Lupasco, 1951.*

[37] *Heisenberg, 1971, pp. 241-242 ;*

the impossibility of a self-enclosed complete theory. Knowledge is forever open.

The logic of the included middle does not abolish the logic of the excluded middle: it only constrains its sphere of validity. The logic of the excluded middle is certainly valid for relatively simple situations, for example, driving a car on a highway: no one would dream of introducing an included middle in regard to what is permitted and what is prohibited in such circumstances. On the contrary, the logic of the excluded middle is harmful in complex cases, for example, within the economical, social, cultural, religious or political spheres. In such cases it operates like a genuine logic of exclusion: good or evil, right or left, heaven or hell, alive or dead, women or men, rich or poor, whites or blacks. It would be revealing to undertake an analysis of xenophobia, racism, apartheid, anti-semitism, or nationalism in the light of the logic of the excluded middle. It would also be very instructive to examine the speeches of politicians through the filter of that logic.

There is certainly coherence among different levels of Reality, at least in the natural world. In fact, an immense self-consistency — a cosmic bootstrap — seems to govern the evolution of the universe, from the infinitely small to the infinitely large, from the infinitely brief to the infinitely long. A flow of information is transmitted in a coherent manner from one level of Reality to another in our physical universe.

The included middle logic is a tool for an integrative process: it allows us to cross two different levels of Reality or of perception and to effectively integrate, not only in thinking but also in our own being, the coherence of the Universe. The use of the included third is a transformative process. But, at that moment, the included third ceases to be an abstract, logical tool: it becomes a living reality touching all the dimensions of our being. This fact is particularly important in education and learning.

2.2.4 The Complexity Axiom: The Universal Interdependence

There are several theories of complexity. Some of them, like the one practiced at the Santa Fe Institute, with the general guidance of Murray Gell-Mann, Nobel Prize of Physics, are mathematically formalized, while others, like the one of Edgar Morin, widely known in Latin America, are not.

In the context of our discussion, what is important to be understood is that the existing theories of complexity do not include neither the notion of levels of Reality nor the notion of zones of non-resistance[38.] However, some of them, like the one of Edgar Morin[39] , are compatible with these notions. It is therefore useful to distinguish between the horizontal complexity, which refers to a single level of reality and *vertical complexity*, which refers to several levels of Reality. It is also important to note that *transversal complexity* is different from the vertical, transdisciplinary complexity. Transversal complexity refers to crossing different levels of organization at a single level of Reality.

From a transdisciplinary point of view, complexity is a modern form of the very ancient principle of universal interdependence. This recognition allows us to avoid the current confusion between complexity and complication. The principle of universal interdependence entails the maximum possible simplicity that the human mind could

[38] *Nicolescu, 1996, 1998, 2000.*

[39] *Morin, 1977, 1980, 1986, 1991,*

imagine, the simplicity of the interaction of all levels of reality. This simplicity cannot be captured by mathematical language, but only by symbolic language. The mathematical language addresses exclusively to the analytical mind, while symbolic language addresses to the totality of the human being, with its thoughts, feelings and body.

It is interesting to note that the combined action of the ontological, logical and complexity axiom engenders values. Therefore, there is no need to introduce values as a 4th axiom[40]. The transdisciplinary values are neither objective nor subjective. They result from the Hidden Third, which signifies the interaction of the subjective objectivity of the transdisciplinary Object and the objective subjectivity of the transdisciplinary Subject.

2.3 Building a New Spirituality

"Spirituality" is a completely devaluated word today, in spite of its etymological meaning as "respiration", in an act of communion between us and the cosmos. There is a big spiritual poverty present on our Earth. It manifests as fear, violence, hate and dogmatism. In a world with more than 10000 religions and religious movements and more than 6000 tongues, how can we dream about mutual understanding and peace? There is an obvious need for a new spirituality, conciliating technoscience and wisdom. Of course, there are already several spiritualities, present on our Earth from centuries and even millennia. One might ask: why is there a need for a new spirituality if we have them all, here and now?

Before answering to this question, we must face a preliminary question: is a Big Picture still possible in our post-modern times? Radical relativism answers in a negative way to this question. However its arguments are not solid and logical. They are in fact very poor and obviously linked to the totalitarian aspect of the political and philosophical correctness expressed by the slogan "anything goes". For radical relativists, after the death of God, the death of Man, the end of ideologies, the end of History (and, perhaps, tomorrow, the end of science and the end of religion) a Big Picture is no more possible. For transdisciplinarity, a Big Picture is not only possible but also vitally necessary, even if it will never be formulated as a closed theory. We are happy that the well-known art critic Suzi Gablik, in her book Has Modernism Failed?[41], joined recently our point of view. The last chapter of her book is entitled "Transdisciplinarity – Integralism and the New Ethics". For her, the essential intellectual change of the last two decades is precisely transdisciplinarity. This change was anticipated by the big quantum physicist Wolfgang Pauli (1900-1958), Nobel Prize of Physics, who wrote fifty years ago: "Facing the rigorous division, from the 17th century, of human spirit in isolated disciplines, I consider the aim of transgressing their opposition […] as the explicit or implicit myth of our present times."[42]

The first motivation for a new spirituality is technoscience, with its associated fabulous economic power, which is simply incompatible with present spiritualities. It drives a hugely irrational force of efficiency for efficiency sake: everything which can be done will be done, for the worst or the best. The second motivation for a new spirituality is

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[40] *Cicovacki, 2003.*

[41] *Gablik, 2004. The first edition was published in 1984.*

the difficulty of the dialogue between different spiritualities, which often appear as antagonistic, as we can testify in our everyday life. The new phenomenon of a planetary terrorism is not foreign to these two problems.

In simple words, we need to find a spiritual dimension of democracy. Transdisciplinarity can help with this important advancement of democracy, through its basic notions of "transcultural" and "transreligious"[43].

The *transcultural* designates the opening of all cultures to that which cuts across them and transcends them, while the *transreligious* designates the opening of all religions to that which cuts across them and transcends them[44]. This does not mean the emergence of a unique planetary culture and of a unique planetary religion, but of a new *transcultural and transreligious attitude*. The old principle "unity in diversity and diversity from unity" is embodied in transdisciplinarity.

Through the transcultural, which leads to the transreligious, the spiritual poverty could be eradicated and therefore render the war of civilizations obsolete. The transcultural and transreligious attitude is not simply a utopian project — it is engraved in the very depths of our being.

This evolution of mentalities could be achieved only if we perform the unification of *Homo religious* with *Homo economicus*.

Homo religiosus probably existed from the beginnings of the human species, at the moment when the human being tried to understand the meaning of his life. The *sacred* is his natural realm. He tried to capture the unseen from his observation of the visible world. His language is that of the imaginary, trying to penetrate higher levels of Reality - parables, symbols, myths, legends, revelation.

Homo economicus is a creation of modernity. He believes only in what is seen, observed, measured. The profane is his natural realm. His language is that of just one level of Reality, accessible through the analytic mind – hard and soft sciences, technology, theories and ideologies, mathematics, informatics.

Transdisciplinary methodology is able to identify the common germ of *homo religiosus* and of *homo economicus* - called *homo sui transcendentalis* in my *Manifesto of Transdisciplinarity*[45]. This identification could be done by taking into account the new relation established by transdisciplinarity between Object and Subject.

In Pre-Modernity the Subject was immersed in the Object. Everything was trace, signature of a higher meaning. The world of the pre-modern human being was magical (see figure).

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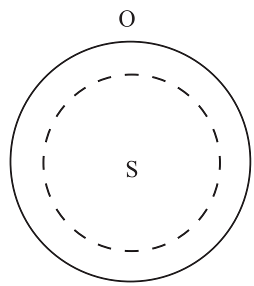
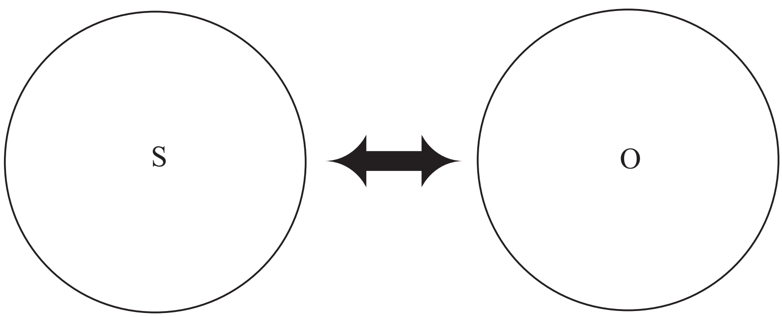
[42]Pauli, 1999, chapter "Science and Western Thinking", p. 178. This chapter was first published in 1955, in Europa –Erbe und Aufgabe, Internazionaler Gelehrtehkongress, Meinz.
[43]Nicolescu, 1996.
[44]Nicolescu, 1996.



S = subject, O = object

In Modernity, Subject and Object were totally separated (see figure) by a radical epistemological cut, allowing in such a way the development of modern science. The Object was just there, in order to be known, deciphered, dominated, and transformed.

Modernity



S = subject, O = object

In Post-Modernity the roles of the Subject and Object are changed in comparison with Modernity and are reversed in comparison with Pre-Modernity: the Object, still considered as being outside the Subject, is nevertheless a social construction. It is not really "there". In looks more like an emanation of the Subject.

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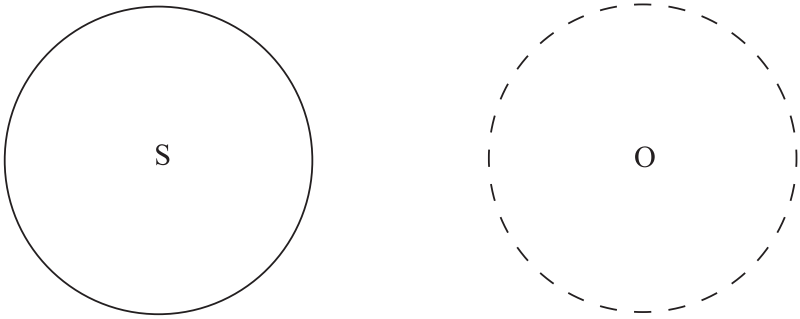
[45]Nicolescu, 1996.

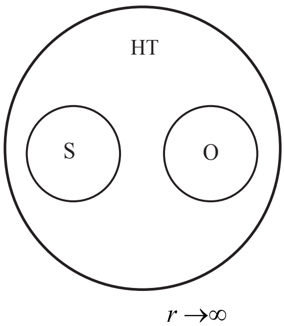
Post-Modernity



S = subject, O = object

Transdisciplinarity leads to a new understanding of the relation between Subject and Object, which is illustrated in the following figure:

Transdisciplinarity



S = subject, O = object, HT = Hidden Third

The Subject and the Object are, like in Modernity, separated but they are unified by their immersion in the Hidden Third, whose ray of action is infinite.

The transdisciplinary Object and its levels, the transdisciplinary Subject and its levels and the Hidden Third define the Transdisciplinary Reality or *Trans-Reality*[46] (see Figure 1)

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[46]*Nicolescu, 2009.*

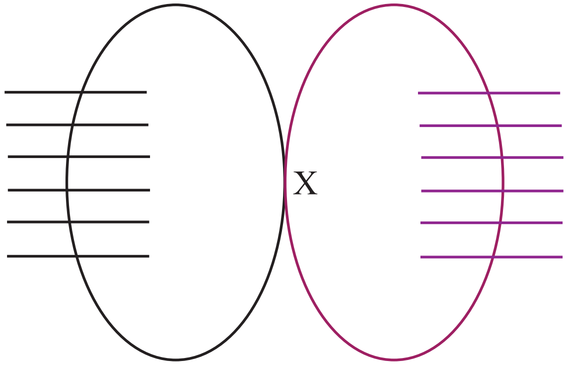

Figure 1. Transdisciplinary Reality.

"*What is Reality*?" - asks Charles Sanders Peirce (1839-1914), a great philosopher, logician, mathematician of the beginning of the 20th century[47]. He tells us that maybe there is nothing at all which corresponds to Reality. It may be just a working assumption in our desperate tentative in knowing. But if there is a Reality - tells us Peirce - it has to consist in the fact that the world lives, moves and has in itself a logic of events, which corresponds to our reason. Peirce's view on Reality totally corresponds to the transdisciplinary view on Reality.

The unified theory of levels of Reality is crucial in building sustainable development and sustainable futures. The considerations made till now in these matters are based upon reductionist and binary thinking: everything is reduced to society, economy and environment. The individual level of Reality, the spiritual level of Reality and the cosmic level of Reality are completely ignored. Sustainable futures, so necessary for our survival, can only be based on a unified theory of levels of Reality. We are part of the ordered movement of Reality. Our freedom consists in entering into the movement or perturbing it. Reality depends on us. *Reality is plastic*. We can respond to the movement or impose our will of power and domination. Our responsibility is to build sustainable futures in agreement with the overall movement of Reality.

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3 Transdisciplinary System Science: Implications for Healthcare and Other Problems of Global Significance

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Abstract

The past decade has witnessed transformational changes on a variety of scientific, technological, and societal fronts. On the scientific front, advances in system science methods, semantic integration techniques, complexity theory, and visual analytics are making it possible to address complex systems problems such as healthcare, climatology, and clean energy. On the technological front, there have been groundbreaking advances such as multicore processors, virtualization and cloud computing, and handheld platforms that have revolutionized the very nature of work. These advances are shaping the research and education agenda for the twenty-first century. On the societal front, technology has transformed how people communicate, share information, socialize, and learn. Facebook and Twitter have transformed our modes and patterns of communication and expectations about the very nature of collaborative work. Crowdsourcing is becoming a popular means for rapid and cost-effective information acquisition, expertise location, and distributed problem solving. These advances have occurred none too soon in that the interconnectedness of today's world has made socio-technical problems increasingly more complex and unquestionably beyond the purview of every single discipline. Not surprisingly, this recognition has spurred the recent surge in interest in transdisciplinary system science research and education. At the heart of transdiscipinary system science are transdisciplinary thinking and collaboration, complex systems modeling and evaluation, and transdisciplinary system science education. This change in mindset is expected

to not only enrich existing disciplines but potentially lead to the creation of entirely new disciplines. Specifically, transdisciplinary system science holds the potential of reaching beyond disciplinary boundaries to resolve incompatibilities and close knowledge gaps between disciplines. The challenge today is to energize communities and institutions of higher learning to address these challenges with a transdisciplinary mindset. This chapter discusses transdisciplinary system science from the perspective of transforming the way we formulate problems, model complex systems, generate hypotheses, design interventions, conduct evaluations, disseminate findings, and continue to learn.

3.1 Introduction

While advances in social networking, collaboration, and crowdsourcing technologies have succeeded in "shrinking" the world or, as Tom Friedman [1] puts it, making it "flat," realworld problems continue to grow in complexity. Not surprisingly, addressing these problems with techniques from a single discipline is becoming increasingly less viable. Today there is a growing recognition that it takes a combination of disciplines to create effective solutions to complex system problems. This fact has not gone unnoticed in the research and education communities as evidenced by the surge in interest in transdisciplinary research and education worldwide.

Despite its obvious allure, operationalizing transdisciplinarity for a particular problem domain (e.g., healthcare) has its share of challenges [2 ,3 , 4, 5]. To begin with, academic and societal viewpoints differ. Fortunately, the academic research and business communities have recognized the need for transdisciplinary research and education frameworks [6]. For example, when it comes to public health, the National Academies (National Academies, 2002) recommend moving from research dominated by a single discipline or a small number of disciplines to transdisciplinary initiatives. They define transdisciplinary research as involving broadly constituted teams of researchers that work across disciplines to develop and answer significant research questions. In these recommendations, transdisciplinary research implies the formation of research questions that transcend individual disciplines and specialized knowledge to solve public health research questions beyond the purview of any single discipline. In transdisciplinary public health research, different specialties seek to combine their expertise (and that of community members) to collectively define health problems and jointly pursue their solutions. The National Academies emphasize that the one qualitatively different and unique aspect of the transdisciplinary "process" is the holistic blending of expert and community inputs to produce greater integration across disciplines than exists today.

Transdisciplinary research implies a dialogue between the different disciplines and theories with a view to advancing both methodological and theoretical developments [7, 8, 9, 10]. This characteristic sets transdisciplinary research apart from some forms of interdisciplinary research which tend to "assemble" different disciplines around particular themes and projects *without making a commitment to changing the boundaries and relations between them.*

Against the foregoing backdrop, the differences among intradisciplinary (or unidisciplinary), multidisciplinary, interdisciplinary, and transdisciplinary research can be identified. Rosenfield [11] defines these different types of research collaboration along a continuum. *Unidisciplinary (or intradisciplinary, as I choose to call it*) collaboration involves researchers from a single discipline working together to address a common

Table 3.1 Collaborative Research Typology (adapted from [6]).

Research Types / Comparison Factors	Intradisciplinary	Multidisciplinary	Interdisciplinary	Transdisciplinary
Collaboration Scope	• Among individuals within a discipline	• Among individuals from different disciplines	• Among disciplines through collaborators	• Across and beyond disciplines without regard to disciplinary boundaries
Specific Focus	• Deeper understanding within a research field (e.g., quantum physics within physics)	• Achieving compatibility in complex problem solving through collaboration	• Creation of integrative solutions potentially resulting in mutual enrichment of disciplines	• Finding hidden connections among knowledge elements from different disciplines
Key Characteristics	• Generally, study same "research objects," (e.g., multiple branches of modern physics) • Tend to have methodologies in common • Tight communications • Mostly speak a common language • Add to the body of knowledge (BOK) of a branch/ discipline	• Harmonize multiple, occasionally incompatible aspects • Integration limited to linking research results • Susceptible to misunderstanding (specialized languages) • Collaborators occasionally unsure about final resolution	• Development of shared concepts, methods, epistemologies for explicit information exchange and integration • Specialization causes knowledge fragmentation, occasionally contradictory knowledge	• Challenge the norm and generate options that appear to violate convention • Look at problems from a discipline-neutral perspective • Employ themes to conduct research and build curricula • Redefine disciplinary boundaries and interfaces • Can produce an entirely new discipline

problem. *Multidisciplinary* collaboration involves researchers from different disciplines working independently or sequentially, each from his or her own disciplinary-specific perspective, to address a common problem. *Interdisciplinary* collaboration involves researchers from different disciplines working jointly to address a common problem and although some integration of their diverse perspectives occurs, participants remain anchored in their own fields. *Transdisciplinary* collaboration involves researchers from different disciplines working jointly to create a shared conceptual framework that integrates and goes beyond discipline-specific theories, concepts, and approaches, to address a common problem. Table 3.1 compares and contrasts these various forms of research initiatives.

It is worth recognizing that transdisciplinarity has its roots in the increasing demand for relevance and applicability of academic research to societal challenges [12]. Not surprisingly, the two popular definitions of transdisciplinary research today center around academic research and societal challenges. The academic research-oriented definition characterizes transdisciplinarity as "*a special form of interdisciplinarity in which boundaries between and beyond disciplines are transcended and disciplines as well as non-scientific sources are integrated.*" The societal challenge-oriented definition characterizes transdisciplinarity as "*a new form of learning and problem-solving involving cooperation among different parts of society (including academia) to meet complex societal challenges. Solutions devised are a result of collaboration and mutual learning among multiple stakeholders.*" As can be seen from the preceding two definitions, there is no standard definition of transdisciplinarity. What is common to both, however, is the desire to achieve unity of knowledge.

3.2 Transdisciplinary Research and System Science

At the outset, it is worth recognizing the subtle differences between system science [13, 14, 15] and transdisciplinary science. One of the objectives of system science is the unification of knowledge residing in different "worlds." In subtle contrast, transdisciplinary science is concerned with *discovering hidden connections* between different disciplines with a view to establishing a common platform for discourse among people from diverse disciplines. Peter Checkland [16] suggests that "what we need is not interdisciplinary teams, but transdisciplinary concepts; concepts which serve to unify knowledge by being applicable in areas which cut across the trenches which mask traditional academic boundaries." Norbert Wiener [17] was among the first to write about the growingly interconnected complex of concepts and models, and about ways of interaction among elements and organizations of complex situations and systems. These perspectives led to the notion of "transdisciplinary synthesis," potentially a new language of interconnected concepts and models applied to reasonably accurate descriptions of complex wholes or "multi-domain ontologies." However, while being cognisant of the ills of hyperspecialization, it is also important to be mindful of the fact that a "theory of everything" does not devolve into a "theory of nothing."

The emergence of transdisciplinary research has been several years in the making as societal problems continue to grow beyond the confines of a single discipline [6]. As noted earlier, transdisciplinary research requires collaboration beyond that addressed by intradisciplinary, multidisciplinary, and interdisciplinary research. Transdisciplinary research is characterized by collaborative interdisciplinary teams engaged in transdisciplinary thinking (i.e., thinking beyond the traditional disciplinary boundaries) to understand and fill knowledge gaps and reconcile incompatibilities that exist among disciplines.

Looking back a few decades, problems tended to be relatively well-circumscribed and amenable to analysis and solution approaches using methods from a single engineering discipline. Years later, led by the aerospace industry, the discipline of systems engineering was born. Systems engineering required people from different disciplines to collaborate to solve problems that were deemed unsolvable using techniques from within a single discipline. With the advent of systems engineering, the emphasis shifted from *applying the right technique* to solve a problem to identifying and *bringing together the right mix of people* from different disciplines to solve complex problems. This was the beginning of multidisciplinary problem-solving which has its roots in multidisciplinary collaboration.

Collaboration among people from different disciplines led to the identification of knowledge gaps and the recognition that some problems required making extensions to the contributing disciplines. Occasionally, entirely new disciplines (e.g., electromagnetics, biomechanics, cognitive engineering, behavioral economics) with new sets of concepts emerge from such collaboration, and become objects of research in their own rights. For example, electromagnetics resulted from the union of electronic and magnetic fields and potentials. Researchers from these two disciplines found that the movement of a charged object created a magnetic field. When this hidden connection between these two disciplines was discovered, it created an entirely new field - - electromagnetics.

Along with cross-fertilization and cross-pollination among disciplines came the recognition that there were incompatibilities among disciplines arising primarily from differences in underlying assumptions and theoretical foundations. These differences, in part, stood in the way of knowledge unification across disciplinary boundaries. It is this recognition that leads to the realization that we need to transcend (i.e., go beyond) disciplines to fill in knowledge voids and harmonize disciplines. This new awakening provides the impetus for transdisciplinary collaboration as a means to achieve knowledge unification across disciplines and domains.

Transdisciplinary research is conducted by interdisciplinary teams working on complex problems requiring expertise in multiple disciplines and knowledge of different domains. The product of such collaboration, if successful, is not merely solutions to complex problem but also unification of knowledge from different domains and disciplines. Ultimately, the goal is unity of knowledge which includes not only knowledge associated with different disciplines but also knowledge between and across disciplines. Figure 3.1 shows how interdisciplinary collaboration can produce transdisciplinary concepts.

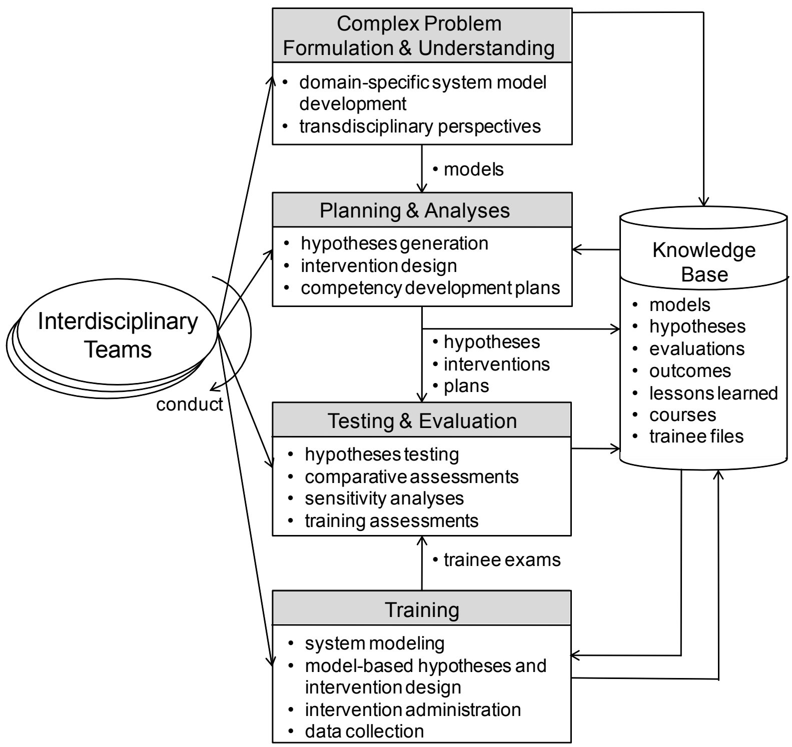

Figure 3.1 Transdisciplinary Concepts Emerge From Interdisciplinary Collaboration.

Transdisciplinary research stands to greatly benefit from a systems perspective and, more specifically, a system science perspective. Systems science is an interdisciplinary field of science that is concerned with the study of complex systems in nature, society, and other sciences. In this paper, systems science is used as a neutral term which

Table 3.2 Analytic versus Synthetic Problem Solving [19].

Comparison Factors	Analytic Problem Solving	Synthetic (Integrative) Problem Solving
Thinking Style	Reductionist	Holistic
Emphasis	Solve by "divide and conquer" strategy	Understand and explain
Solution Strategy	Compose whole solutions from partial solutions	Whole solution greater than the some of the partial solutions
Shaping Mechanism	Command and control	Incentivize and influence
Examples	Classification, diagnosis, troubleshooting	Planning, design, architecting
Representative Systems	Aircraft, ship, tank, automobile, PDA	Internet, healthcare, energy grids

subsumes a variety of systems-related fields such as systems theory, systems thinking, system dynamics and system modeling. Its focus is on holistic thinking and generative, iterative processes. Its generative nature leads to the creation of novel hypotheses which is in sharp contrast to reductionist approaches that begin with pre-determined, specific hypotheses. A variety of modeling approaches are subsumed within the system modeling rubric including system dynamic models, concept graphs, agent-based modeling, and macro-micro simulation models. The infusion of system science into transdisciplinary research provides the means to model complex problems, and use the model to: generate transdisciplinary hypotheses; inform and guide the development of interventions; develop evaluation criteria to assess the impact of interventions; analyze the sensitivity of interventions to sociocultural and environmental factors; and capture lessons learned with contextual information.

Systems science also stands to benefit from transdisciplinary research in important ways. Transdisciplinary thinking and collaboration seek to challenge traditional disciplinary boundaries with the intent of uncovering hidden connections. Such discoveries can potentially expand the discourse about the complex system and lead to enhancement of system models. The enhanced models provide a platform for he generation of novel transdisciplinary hypotheses and construction of transdisciplinary interventions.

What distinguishes transdisciplinary system science-oriented thinking from traditional reductionist approaches is that transdisciplinary thinking emphasizes lateral or associative thinking [18], often relying on metaphors and analogies to enhance problem understanding. In particular, transdisciplinary approaches employ integrative (or synthetic) problem solving as opposed to analytic problem solving typically employed by reductionist approaches [6, 19]. Table 3.2 compares and contrasts analytic and synthetic problem solving that underlie traditional (reductionist) and transdisciplinary (holistic) approaches.

3.3 Stimulating Transdisciplinary Thinking and Modeling

Transdisciplinary research requires a transdisciplinary mindset [6]. A transdisciplinary mindset is one that is open to questioning disciplinary assumptions, and one that is willing to reach out to other disciplines to find solutions to problems [6]. Table 3.3 presents some of the key characteristics of a transdisciplinary mindset.

In recent years, researchers are turning to *transdisciplinary research frameworks and system-based methodologies* to overcome the limitations of today's research infrastructure. In particular, the National Institute of Child Health and Human Development,

Table 3.3 Characteristics of Transdisciplinary Mindset (adapted from [6]).

- ***Actively look for and exploit synergies*** among disciplines
  - – e.g., decision theory and artificial intelligence
- ***Seek out appropriate analogies*** that help with problem understanding and problem solving
  - – e.g., biological analogy exploitation – human immune system as a model for cybersecurity
- ***Frame the problem in a larger context*** to open up collaboration scope
  - – e.g., BMW's boxfish-like concept car was a result of collaboration between engineers and marine biologists
- ***Examine the problem as an outsider*** to develop new perspectives
  - – looking beyond entrenched thinking can open up the option space (i.e., possibilities)
- ***Formulate the problem from different perspectives*** to gain novel insights
  - – perspectives could include technical, organizational, social, cultural, and environmental
- ***Envision outcomes*** to determine what incentives to apply and what constraints to relax
  - – a "reality check" can cause the relaxation of constraints imposed by an entrenched mindset
- ***Strive for semantic interoperability*** among disciplines
  - – develop multi-domain ontologies to "smooth out" seams among disciplines
  - – reconcile assumptions and theories across disciplines (to the degree possible)
  - – create a shared vocabulary to address complex problems
  - – relax disciplinary boundaries to accommodate new concepts
- ***Explicitly formulate transdisciplinary tradeoffs*** by reaching beyond disciplinary boundaries
  - – encourage team to view problems in a new light ("open mental locks")
- ***Employ model-based approaches*** to generate transdisciplinary hypotheses and interventions
  - – develop complex systems models using, for example, system dynamics modeling
  - – exercise these models to generate hypotheses and interventions and define metrics

National Cancer Institute, Office of Behavioral and Social Sciences Research, and National Institute of Health are actively soliciting research grant applications. For example, NICHHD is interested in establishing a center of excellence for childhood obesity research and training based on a transdisciplinary system science-oriented framework and methodologies with the intent of capturing etiological complexity of childhood obesity and the potential impact of environmental and/or policy interventions. Transdisciplinary system science is being viewed as the means to go beyond traditional disciplinary boundaries and thereby overcome the limitations of existing research infrastructures. In particular, systems-oriented research is viewed as key to overcoming reductionist thinking and generating sustainable solutions within the broader social, cultural, and economic environment.

In healthcare, transdisciplinary collaboration is critical to pushing the boundaries of intervention approaches and, in so doing, contribute to and expand the frontiers of existing science and/or create new science [20, 21]. In particular, transdisciplinary collaboration is key to the formulation of cross-disciplinary, cross-level research hypotheses that, in turn, enable the creation of effective structural, environmental, or policy-related interventions. Ultimately, cross-disciplinary, cross-level hypotheses are key to creating superior structural, environmental, and policy level interventions that are key to realizing sustainable solutions in the public health arena.

In this regard, systems modeling using systems dynamics, plays a key role in breaking the traditional "linear systems thinking" mindset that invariably attenuates weak effects of meso-level interventions on system behavioral trends. From an epistemological perspective, traditional approaches tend to bias research based on linear cause-effect models on the most proximate cause-effect relationships and treat the distal effects as sources of noise. However, from a systems perspective in which one can have nonlinear feedback relationships, weak relationships within a feedback loop can accumulate over time to eventually become the main driver of system behavior [22]. This is "emergent" behavior which cannot be reduced to and reflected in the properties of the individual subsystems/components, but can only be understood by viewing the system as a whole (i.e., holistically). This phenomenon complicates the evaluation of policy interventions. Consequently, new methods, processes, and tools are needed to handle the complexities of the system. For example, in the world of childhood obesity control, without such methods it is rarely possible to have an adequate theory for generating hypotheses about the complex ways that community level interventions and their sequence and timing can affect outcomes over time.

When a complex system is viewed from a system dynamics perspective, the system is characterized as a set of coupled, nonlinear differential equations. With this characterization, it has been found that most parameters exert some influence, however weak, on the magnitude of the trends, and only a few parameters exert sufficient influence to actually alter the qualitative shape of the trajectory being studied. It is interesting to note that most model parameters can vary significantly (50% in either direction) without qualitatively impacting the shape of the system trajectory [23]. It is equally important to note that the influence of feedback mechanisms changes over time; that is, the system evolves thereby confounding previous explanations of behavior using traditional methods. From an epistemological perspective, this does not mean that all other mechanisms are not contributing to shaping behavior in some way, but rather that their contributions are small. For example, with respect to childhood obesity control, these minor mechanisms are likely to influence how fast obesity trends are increasing, but are not sufficiently influential to determine whether obesity trends show an increase or decrease in childhood obesity [23].

3.4 Transdisciplinary System Science (TSS) Application to Public Health

3.4.1 Transdisciplinary System Science Framework

Healthcare has been described as a complex adaptive system [24, 25, 26, 27, 28] that is not amenable to being managed by traditional "command and control" methods. Instead, this complex adaptive system can be shaped and influenced through appropriately designed interventions and incentives. These interventions and incentives show up in the form of policy changes, new regulations, promotional programs, and in the form of guidance counseling, therapy, advertisements, and training at the community and individual levels. The TSS Framework presented in this paper is an example of viewing a complex enterprise (e.g., healthcare) through a transdisciplinary lens, and analyzing and evaluating the behavior of the enterprise to a variety of interventions and incentives through a system science lens. Figure 2 presents the overall TSS Framework. The key elements of this framework are discussed next.

TSS Blackboard. This is the shared global database that mediates information among the various stakeholders, and maintains status of plans, hypotheses, interventions, evalu-

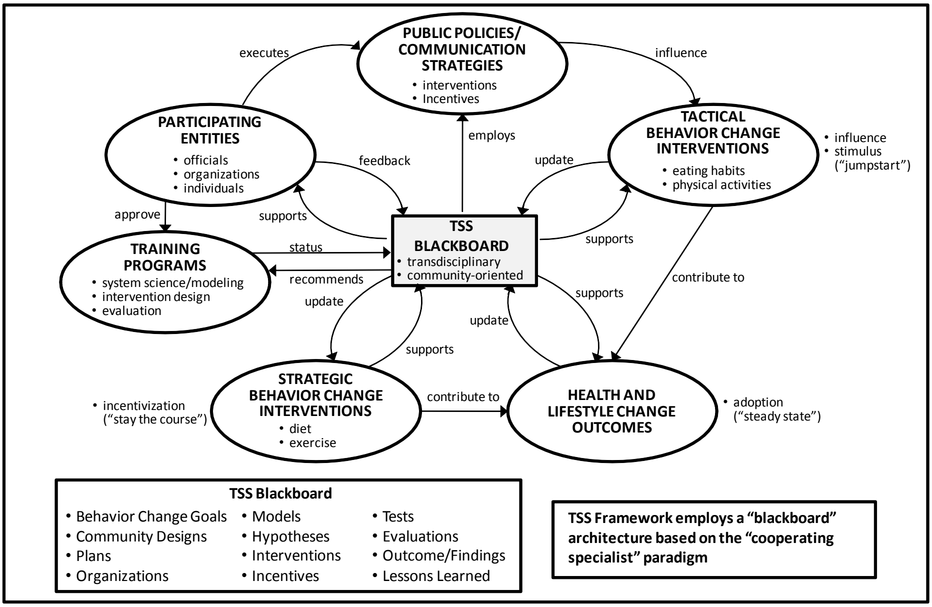

Figure 3.2 The TSS Framework: Coordination Perspective.

ations, and outcomes that comprise the TSS Framework (Figure 3.2). The blackboard architecture, based on the "cooperating specialists" paradigm [19] ensures that the various users of the TSS Framework interact solely with the blackboard without having to worry about the other "specialists" using or contributing to the blackboard. This feature makes the TSS Framework totally scalable while ensuring that the addition/departure of a "specialist" does not require changes to the other elements or disrupt the integrity of the overall architecture. This feature is especially desirable as new "partners" come into or leave the overall enterprise.

Participating Entities. The participating entities range from individuals, advisory groups, and officials, to national and international organizations and programs. These entities contribute resources and information to the TSS Framework and draw on informational resources provided by the framework.

Public Policies and Communication Strategies. These include public policy changes, new communication strategies, and behavior change incentives. These strategies are intended to accomplish short-term behavior changes, produce longer-term behavioral shifts, and, ultimately, contribute to sustainable health and lifestyle changes.

Tactical Behavior Change Interventions. These interventions, focused on short-term changes, employ strategies that take the form of some kind of stimulus that "jumpstarts" the process of change, where the desired change could be, for example, in eating habits and physical activities.

Strategic Behavior Change Interventions. These interventions, focused on achieving longer-term changes, employ incentives that ensure that the community and population

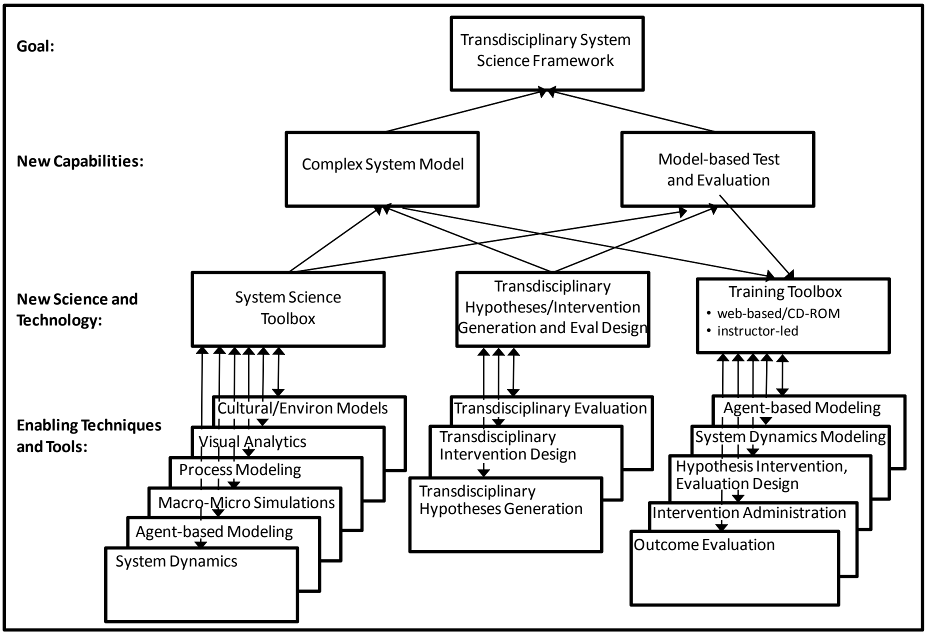

Figure 3.3 TSS Framework: Development and Application Perspective.

can "stay the course." Examples of staying the course are staying on a healthy diet and exercise regimen that can ultimately become ingrained in the community or population.

Training Programs. These initiatives, that are tailored for each community and population, are intended to exploit a variety of methods and media to teach community members, trainers, community organizers, health advocates, family members in healthful lifestyle practices. They are also intended to teach public health domain system modelers in a variety of modeling methods (e.g., concept graphs, system dynamics, agent-based simulations, Markov models, macro-micro simulations) that can inform the development of transdisciplinary research hypotheses, and transdisciplinary interventions. The training programs are also intended to target administrators and community organizers responsible for administering interventions and evaluating their impact.

Health and Lifestyle Change Outcomes. These are sustainable results that reflect the adoption of the behavioral changes by communities and populations. These imply that the communities/populations have reached "steady state" and are highly unlikely to revert to old bad habits and behaviors that contribute to, for example, childhood obesity.

3.4.2 TSSF Application to Complex Healthcare Problem

Figure 3 presents the development and application perspectives of TSSF for a complex healthcare problem (e.g., childhood obesity control). As shown in Figure 3.3, starting with a basic set of enabling modeling techniques and tools from different disciplines (e.g., system dynamics, computer science, cognitive science, social sciences), we can

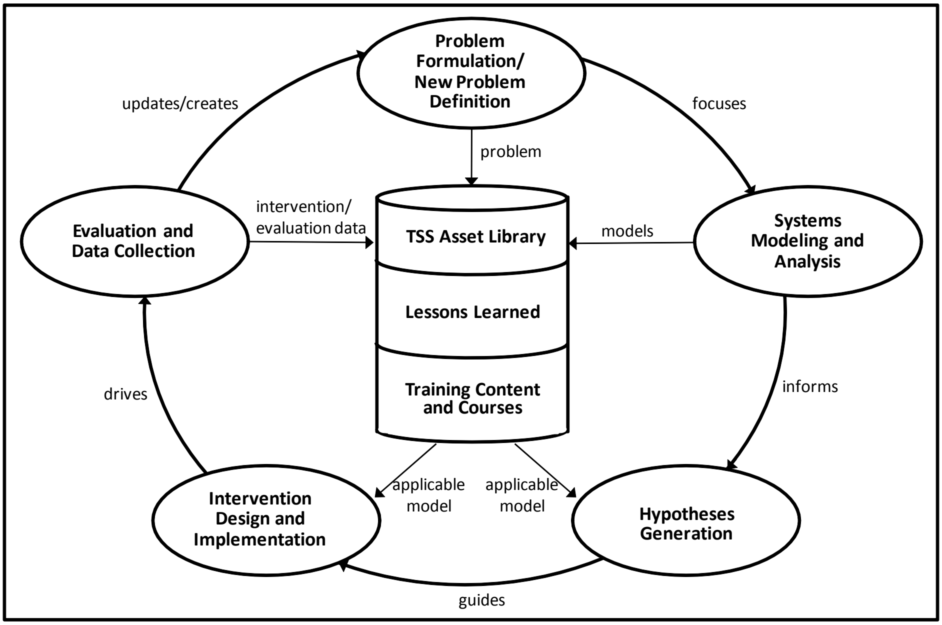

Figure 3.4 TSS Model-driven Research and Training Development Process.

combine and apply these tools in new and novel ways to create the systems science "toolbox." This toolbox is used to create a systems model for the complex problem (e.g., childhood obesity control). This model provides the basis for testing and evaluating various transdisciplinary hypotheses and interventions. The results of model-based test and evaluation are used to tailor the training toolbox that is used to teach systems modeling, transdisciplinary hypotheses generation, intervention design and implementation, intervention administration, and outcome evaluation. The training toolbox supports both web-based and instructor-led training strategies. The trainees include local community organizers and community members involved in mitigating complex health problems.

3.4.3 The TSS Process Model

The TSS process begins with Problem Formulation followed by Systems Modeling and Analysis (Figure 3.4). The outputs of these activities are system models, which inform and guide transdisciplinary hypotheses generation, intervention design and implementation, data collection, and impact evaluation. The latter prompts formulation of new problems, generation of new hypotheses, and design of new interventions at multiple levels. As this closed-loop TSS process is undertaken, transdisciplinary system science assets are generated and persistently stored in the TSS Assets Library (TSSAL). Concurrently, training material is developed for teaching communities (local and international) in how to formulate problems, how to model systems using a variety of techniques (e.g., concept graphs, system dynamics models, agent-based models, and parametric models), how to design interventions at multiple levels (policy, socio-cultural, biological), and how to collect data and evaluate results. The evaluation results can initiate a new cycle starting with new problem definition.

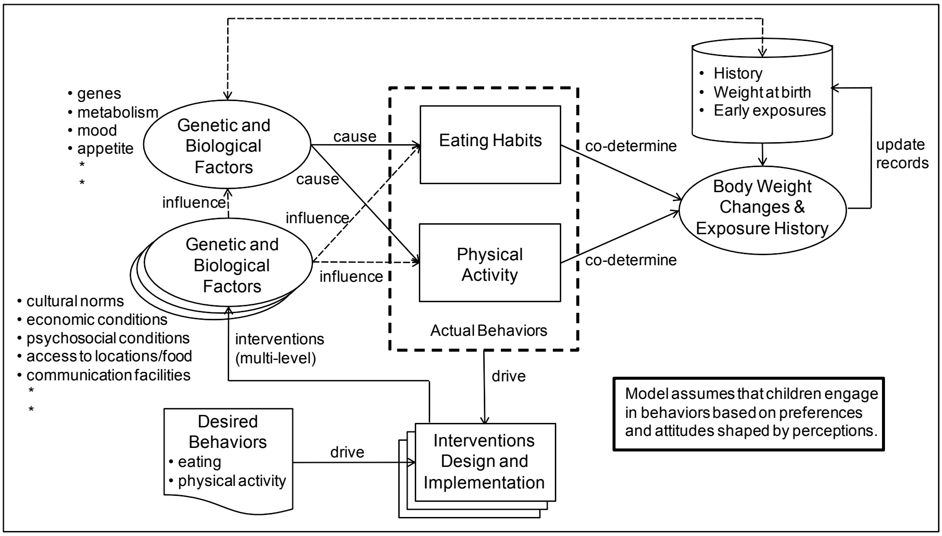

Figure 3.5 Systems-oriented Multi-level Model for Childhood Obesity Control.

The TSSAL contains models, tools, hypotheses, interventions, stakeholders, lessons learned about specific interventions in terms of their immediate, intermediate, and long-term impacts. The lessons learned are intended to inform and guide users of the TSSF in undertaking other major public health initiatives. The TSSAL also contains training content and courseware. The courseware includes learning objectives, instructional strategies, tests/quizzes and evaluation metrics. The content is stored as shareable content objects (SCOs) in accord with the SCORM standard. These objectives can be reused and repurposed for a variety of training applications [29], thereby saving time and money in training development. In short, the vision of TSSAL is that of a repository of TSS models, tools, facts, experiments, and outcomes, that can be institutionalized internationally to support global health initiatives.

3.4.4 Systems-oriented Model of Childhood Obesity

Figure 3.5 presents a systems-oriented, multi-level, multi-perspective model for childhood obesity problem analyses and intervention design to achieve desired health outcomes. The model is based on the recommendation of Glass and McAtee [30], who note that since social factors (e.g., social inequality, poverty) are difficult to study from a traditional epidemiologic perspective, they ought to be viewed as risk regulators or influencers of obesity-related behaviors (at the individual, community, and public policy levels). For example, food distribution systems alter obesity likelihood at the population level that, in turn, lead to different rates of obesity. The challenge is to identify the key risk regulators within the social, physical, cultural, and economic environments that influence obesity. The concept of risk regulators overcomes the lack of clarity about the key obesity drivers, their locations, and the determination of the optimal intervention points. The multiple levels of the model are intended to acknowledge both the macro-level forces and the local environmental factors that govern/influence eating habits and physical activity. Huang et al [31] explain this influence chain by describing the temporally and spatially distal forces at the macro level that cascade through organizations, through systems of food distribution, through policies and pricing, and eventually shape the perceptions of people. Examples of the intervening variables for obesity include cultural norms, social networks, local food availability, food prices and taxes, physical activity amenities, psychosocial stress, and economic conditions. These factors can potentially act through neurologic/epigenetic regulatory pathways to affect behavior and generate feedback loops to higher levels in the system [31].

3.4.5 Setting Up a Transdisciplinary Research and Training Organization

Transdisciplinary collaboration is the hallmark of a transdisciplinary research organization. Setting up such an organization requires incorporating transdisciplinary perspectives into all aspects of the organization including organization design, research problem formulation, hypotheses generation, intervention design, intervention efficacy evaluation, and training. Transdisciplinary collaboration involves multiple stakeholders and multiple specialists with different expertise areas (e.g., business operations, system science, system modeling, obesity control, policy design, environmental sciences, social sciences, experimental design) working closely to: a) develop the vision and mission statement for the research and training organization; b) architect the organization to facilitate transdisciplinary research and education; c) conduct domain analysis; d) model the complex system at the community level; e) generate transdisciplinary hypotheses; f) design and implement transdisciplinary interventions; and g) evaluate efficacy of the interventions, and achievement of the organization's objectives. The infusion of transdisciplinary systems thinking and collaboration in the design and operation of a research and education organization is presented next.

Vision and Mission Definition involves developing the transdisciplinary research and education agenda of the organization and the impact it is expected to have in both the short-term and longer-term on: a) the organization's goals and objectives; and b) health outcomes (e.g., impact on childhood obesity rates).

Transdisciplinary Organization Design involves creating an organization architecture that lends itself to supporting transdisciplinary research and education. This includes the leadership of the organization, the creation of distributed collaborative teams, the emphasis on capacity building including training, setting stretch goals that push the boundaries of intervention approaches, and laying the groundwork for a sustainable area of new science.

Domain Analysis involves analyzing the target problem domain form transdisciplinary perspectives. Thus, the problem domain of childhood obesity prevention and control would be analyzed from a process perspective, socio-cultural perspective, environmental perspective, economic and educational perspective, epidemiology perspective, and intervention design perspective. As importantly, the analysis of interactions around macroenvironmental, macrosocial, and biological factors would be studied from a transdisciplinary perspective.

System Modeling involves modeling the complex system at different levels of abstraction and from different perspectives using a variety of systems science approaches and system modeling tools (e.g., concept graphs, system dynamics, process modeling, behavioral modeling at individual, organizational, and community levels) and in the presence of a variety of modifiers (e.g., social, cultural, environmental, economic, educational). The overall purpose of system modeling is to: a) enable the simultaneous examination of influences of a wide range of biological and socio-environmental factors on obesity behavior and outcomes; b) enable the evaluation of downstream impacts of environmental/policy interventions; and c) provide content for training a cadre of system scientists to address complex socio-technical problems in various significant domains such as public health and energy.

Iterative Hypotheses Generation involves employing the complex system model to generate transdisciplinary hypotheses spanning a variety of interventions (e.g., environmental and policy) including training. The iterative nature of transdisciplinary hypotheses generation is intended to extend disciplinary boundaries and occasionally uncover hidden connections among knowledge elements from different disciplines, thereby providing new and useful insights for problem understanding and intervention design.

Iterative Intervention Design and Implementation involves exploiting the system model to develop effective interventions (e.g., environmental, policy, training) for a particular environment (i.e., geography, demographics, economic status, social and environmental conditions), and implementing the interventions in a culturally-aware, environmentally-conscious fashion.

Evaluation encompasses *intervention evaluation* (i.e., efficacy of the intervention in the target environment), *training evaluation* (i.e., improvements in trainee population's ability to model, design interventions, conduct surveys, and evaluate impacts), and *organizational evaluation* (i.e., the evaluation of an organization's ability to make its target objectives). The latter include trainee throughput, intervention outcomes (short-term, long-term), as well as an organization's ability to generate sustainable revenue streams through research, operation and training.

Curriculum Design and Training encompasses creating the right content (i.e., training material) and training strategies to teach target populations about how to engage in tarnsdisciplinary thinking, design communities, generate plans, model complex systems at various levels (e.g., the community level), generate transdisciplinary interventions, develop evaluation questionnaires and schemes, and develop evaluation metrics.

3.5 Towards a Transdisciplinary System Science Research and Eucation Agenda

The previous section presented the key concepts behind a transdisciplinary system science research framework and an illustrative example. This section provides strategies for creating a transdisciplinary system science-oriented research and education agenda.

3.5.1 TSS Research Agenda

A research agenda for TSS research needs to be driven by problems of high complexity and scale that elude traditional approaches [6, 32]. Preferably, these problems should be of global significance to garner international attention. Such problems tend to be complex socio-technical problems that span multiple disciplines, domains, societies, and cultures. They invariably require harmonizing terminologies across the contributing disciplines. Some of the earlier work in transdisciplinary education and research in the engineering disciplines was in relation to design and process science [33, 34]. Examples of such problems are disaster response, childhood obesity prevention and control, and global security and safety. The fourteen Grand Challenges of the National Academy of Engineering (http://www.engineeringchallenges.org/ cms/challenges.aspx) all involve complex socio-technical problems at some level. Once such problems have been formulated from different perspectives, the relevant disciplines that potentially contribute to their solution need to be identified and researchers from the relevant disciplines assembled and incentivized to participate and stay the course. Thereafter, interdisciplinary collaboration among these researchers needs to begin. This process can potentially move disciplinary boundaries, resolve incompatibilities among disciplines, and occasionally result in enhancing theories. The resultant body of knowledge (BOK), after verification and validation by transdisciplinary teams, can be incorporated into the TSS educational agenda.

3.5.2 TSS Education Agenda

The TSS education agenda, in large part, "flows" from the TSS research agenda. It begins with the delineation of complex system characteristics that are beyond traditional intradisciplinary and multidisciplinary approaches. It needs to harness findings from interdisciplinary research to define new concepts and topics for inclusion in the curricula of the contributing disciplines. Thereafter, potential barriers to transdisciplinary education need to be identified and discussed along with the role of specific technologies (e.g., semantic technologies) to potentially overcome these barriers. Finally, a set of canonical problems that requires the creation, use, refinement and deployment of transdisciplinary "bridges" (e.g., multi-domain ontologies) needs to be included in the overall educational agenda to increase the students' understanding of problems requiring TSS solutions.

3.6 Conclusions

As science moves deeper into the workings of the universe, we will increasingly develop models and methods that unite disciplines. Electromagnetics, biostatistics, cognitive engineering, psychophysiology and medical informatics are but a few examples of this phenomenon. Today, we can engineer materials atom by atom, working very nearly at the boundary between matter and energy. At this level, disciplinary distinctions become almost arbitrary as physics, chemistry, biology and engineering begin to converge upon shared possibilities [35]. The "promise of converging spaces" can be profound and far-reaching. Some of the pressing challenges that can be addressed through such convergence include: mitigating the damage we inflict on the environment; producing new materials to support the rapid development of worldwide infrastructure, defending ourselves against escalating chemical-biological threats; and increasing computing power while reducing size and cost. Such pressing priorities are beyond the purview of a single discipline, a single institution, or even a single society or culture.

This is the essence of the TSS approach. However, the promise of transdisciplinarity comes with its fair share of challenges. To begin with, any transdisciplinary approach requires "going beyond the laboratory" and into the realm of politics. No far-reaching reform or advance is possible without getting into the realm of politics. Very simply, politics is the process by which humans express desires, establish priorities, and allocate resources [35]. The key question, of course, is whether politics will advance or hinder the advance of promising technologies. Clearly, while these types of questions are addressed in the realm of politics, scientists must step forward to represent the possibilities that may otherwise go unvoiced, unnoticed, or worse yet, misunderstood.

For TSS research discussions to go beyond the abstract into making a difference to pressing issues in the realworld, researchers need to initially identify regional problems and issues at various scales and, after demonstrable successes, elevate their sights to issues of national and global significance. Regional issues can be identified in a variety of venues such as energy conservation and use, environment management systems, global climate change management, healthcare, sustainable development, and educational reform. Once such problems have been identified, an appropriate mix of disciplinary breadth and depth can be specified based on the theme, issue or problem addressed. It is almost inevitable that addressing such socio-economic and socio-political problems will require linking specific scientific disciplines with humanities.

However, realizing a TSS educational curriculum requires several changes at the content, instruction, and institutional levels. To begin with, course content needs to be focused on those real problems and issues that are not amenable to solution or resolution from within a single discipline and that require interdisciplinary teams. Second, there is a need for faculty members with an open mind who are willing to look for and discern emergent connections among disciplines and develop new insights. Third, educational institutions need to not only be accepting of this paradigm shift but, in fact, create an environment that attracts and incentivizes TSS educators and researchers. Fourth, the curricula need to be viewed not merely from the perspectives of depth and breadth but from a thematic perspective. The syllabus needs to be theme-focused, integrated with the appropriate disciplines, and at a level of depth and breadth consistent with the theme. Fifth, since the internet has dramatically facilitated the conduct of transdisciplinary research [36], it should be exploited in web-based learning and distance learning programs. Finally, concrete examples of theme-related transdisciplinary solutions and experiences need to be covered to develop transdisciplinary thinking skills. In conclusion, the time has come for us to begin exploiting the "flatness" of this world with open minds and a commitment to TSS research and education, the next frontier in the intellectual and societal growth of human kind.

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4 Understanding of Transdiscipline and Transdisciplinary Process

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Abstract

In July 2007, NIOSH sponsored Prevention through Design (PtD) Workshop, which concluded that there was a critical need to include PtD in the education of engineers. The main objective of this module is to introduce the concept of Prevention through Design to prevent occupational injuries, illnesses, and fatalities to freshman engineers in the introduction to design course. Students should emerge from this transdisciplinary education with a broad perspective of occupational safety and health needs in the design process to prevent or minimize the work-related hazards. Similarities between transdisciplinary process and Prevention through Design concept also introduced and discussed.

4.1. Introduction

During the last decade, the number of complex problems facing engineers has exploded, and the technical knowledge and understanding in science and engineering required to address and mitigate these problems is rapidly evolving. The world is becoming increasingly interconnected as new opportunities and highly complex problems connect the world in ways we are only beginning to understand. When we do not solve these problems correctly and in a timely manner, they rapidly become crises. Problems, such as energy shortages, pollution, transportation, the environment, natural disasters, safety, health, hunger and the global water crisis, threaten the very existence of the World as we know it today. Recently, fluctuating fuel prices and environmental concerns have sent car manufacturers in search of new, zero polluting, fuel-efficient engines. None of these complex problems can be understood from the sole perspective of a traditional discipline. The last two decades of designing large–scale engineering systems have demonstrated that neither mono–disciplinary nor inter– or multi–disciplinary approaches provide an environment that promotes the collaboration and synthesis necessary to extend beyond existing disciplinary boundaries and produce truly creative and innovative solutions to large–scale, complex problems. These problems include not only the design of engineering systems with numerous components and subsystems which interact in multiple and intricate ways; they also involve the design, redesign and interaction of social, political, managerial, commercial, biological, medical, etc. systems. Furthermore, these systems are likely to be dynamic and adaptive in nature. Solutions to such unstructured problems require many activities that cut across traditional disciplinary boundaries: that is, transdisciplinary research and education.

The results of transdisciplinary research and education are: emphasis on teamwork, bringing together investigators from diverse disciplines, developing and sharing of concepts, methodologies, processes, and tools; all to create fresh, stimulating ideas that expand the boundaries of possibilities. The transdisciplinary approach creates a desire in people to seek collaboration outside the bounds of their professional experience to make new discoveries, explore different perspectives, express and exchange ideas, and gain new insights.

The main objective of this paper is to introduce the concept of transdisciplinary process: Prevention through Design to prevent occupational injuries, illnesses, and fatalities.

4.2 Discipline

For the many years since the 1950s, the integration of research methods and techniques across disciplines has been of great interest in the social and natural sciences [1]. A particular area of study is called a "discipline" provided it has cohesive tools, specific methods and a well developed disciplinary terminology. Since 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. Many distinguished researchers and educators contributed to the development of transdisciplinary education and research activities [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19].

Multidisciplinary activities involve researchers from various disciplines working essentially independently, each from their own discipline specific perspective, to solve a common problem. Multidisciplinary teams do cross discipline boundaries; however, they remain limited to the framework of disciplinary research.

In Interdisciplinary activities, researchers from diverse disciplines work jointly on common problems by exchanging methods, tools, concepts and processes among them to find integrated solutions. Both multidisciplinary and interdisciplinary activities overflow discipline boundaries but their goal remains within the framework of disciplinary research.

In Interdisciplinary activities, researchers from diverse disciplines work jointly on co mon problems by exchanging methods, tools, concepts and processes among them to find i tegrated solutions. Both multidisciplinary and interdisciplinary activities overflow discipline boundaries but their goal remains within the framework of disciplinary research.

4.3 Defining Transdisciplinarity

In the German-speaking countries the term transdisciplinarity is used for integrative forms of research [20]. Transdisciplinary education and research programs take collaboration across discipline boundaries a step further than do multidisciplinary and interdisciplinary programs. The transdisciplinary concept is a process by which researchers representing diverse disciplines work jointly to develop and use a shared conceptual framework to solve common problem. A central hallmark of transdisciplinary research is the loosening of theoretical models and the development of a new conceptual synthesis of common terms, measures, and methods that produce new theories and models [21]. The three terms of: multidisciplinary, interdisciplinary and transdisciplinary, are often defined differently among researchers and educators.

Nicolescu (2005) stated that transdisciplinarity concerns that which is at once between the disciplines, across the different disciplines, and beyond all disciplines [22].

Klein (2004) defined the terminology of multidisciplinary, interdisciplinary and transdisciplinary approaches as [8]: "Multidisciplinary approaches juxtapose disciplinary/professional perspectives, adding breadth and available knowledge, information, and methods. They speak as separate voices, 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."

Hadorn, H. G et al., stated that: "Transdisciplinary research is research that includes cooperation within the scientific community and a debate between research and the society at large. Transdisciplinary research therefore transgresses boundaries between scientific disciplines and between science and other societal fields and includes deliberation about facts, practices and values," [23].

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 [24].

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 [25].

"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" [26].

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 [19]:

Transdisciplinarity is a development of new knowledge, concepts, tools & technologies shared by researchers from different family of disciplines (Social science, natural science, humanities and engineering). It is a collaborative process of a new way of organized knowledge generation and integration by crossing disciplinary boundaries for designing and implementing solutions to unstructured problems.

Transdisciplinary Knowledge is a shared, common collection of knowledge from diverse disciplinary knowledge cultures (engineering, natural science, social science and humanities).

The Transdisciplinary Research Process can be defined as collaboration among scholars from diverse disciplines to develop and use integrated conceptual frameworks, tools, techniques and methodologies to solve common unstructured research problems. Transdisciplinary research leads to a creation of new paradigms and provides pathways to new frontiers.

Key Centers of Attention and Characteristics of Transdisciplinary Research Are:

- Use of shared concepts, frameworks, tools, methodologies and technologies to solve common unstructured research problems,
- Eliminates disciplinary boundaries for strong collaboration,
- Redefines the boundaries of natural science, social science, humanities and engineering by bridging them,
- Leads for the development of new knowledge, shared common conceptual frameworks, tools, methodologies and technologies.

4.4 Multidisciplinary, Interdisciplinary and Transdisciplinary Case Study [19]

Wind power promises a clean and inexpensive 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-weight devices to heavy, material-intensive drag devices and finally to the increased use of light-weight, 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. 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 [27].

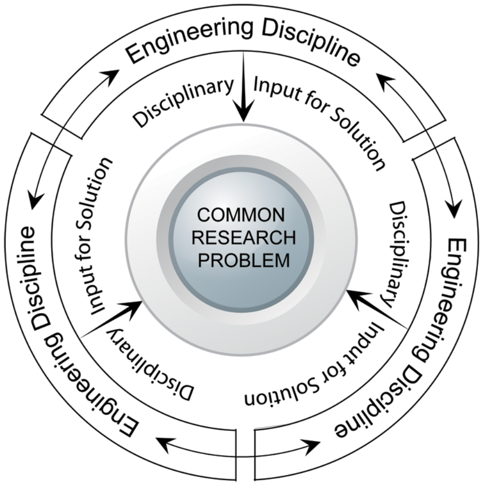

Figure 4.1 Multidisciplinary Research Process.

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. It is interesting to note that some of these units have been in operation for more than a hundred years [28].

A wind turbine system design consists of sub-systems to catch the energy of the wind, to point the turbine into the wind, to convert mechanical rotation into electrical power; as well there are 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. The first approach that comes to mind could be the multidisciplinary research process.

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.

Assume that engineers from diverse disciplines attempt to design a wind turbine. As shown in Figure 4.1, the common research problem is to design a wind turbine. 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, electric engineers work on power transmission and control system design and finally, wind engineers may work on rotor blade design and deliver their sub-product design independently and the whole system will be put together. The question is: is

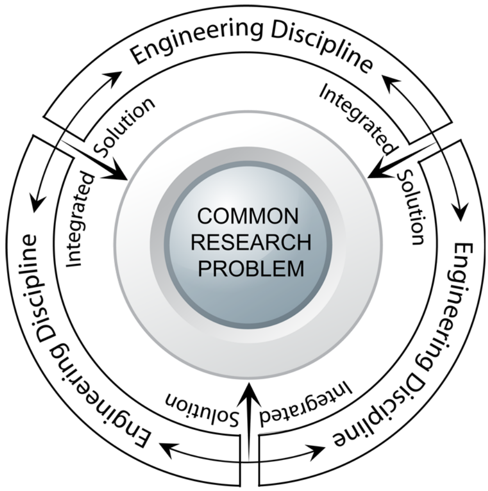

Figure 4.2 Interdisciplinary Research Process.

this process providing an optimum design? The answer is obviously no! Maybe better collaboration and organization is necessary for this kind of complex system design.

If the research approach is interdisciplinary, as shown in Figure 4.2, 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, after the sub-product designs are delivered independently, the entire system can then be assembled. The question is: is this process providing an optimum design? Again, the answer perhaps would be no.

Although wind power promises a clean and inexpensive 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.

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.

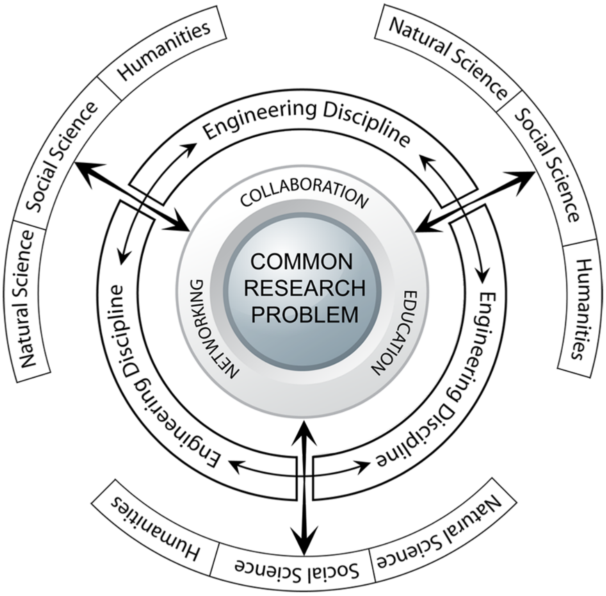

Figure 4.3 Transdisciplinary Research Process.

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.

As shown in Figure 4.3, transdisciplinary research process involves not only crossing engineering disciplinary boundaries but also requires crossing families of disciplinary boundaries (engineering, social science, natural science, and humanities). Social Sciences and the Humanities bring an abundance of knowledge on cultural, economic and social growth and advancement as well as on social system. Therefore, they provide an important input to decisions being made relative to current problems and challenges. The Humanities play an important role putting to beneficial use new findings in engineering and the natural sciences. For example, natural scientists work together with researchers in the humanities to discover archeological objects and determine their age.

In the case of wind turbine design, 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 the environment and nearby communities of people to guide reiteration of their design.

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. In other words, designers should make reasonable efforts to "design out" or minimize hazards and risks early in the design process.

Further, researchers from diverse disciplines should collaborate and 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.

Continuous education and encouragement is required to development a spirit of collaboration among the research members in order to solve complex problems. Through educational activities that focus on such areas as research team management, problem solving, establishing research goals, optimizing the use of resources, and supporting each other, members of the research team learn to work together more effectively. In other words, team members provide mentoring and support to each other. For transdisciplinary teams to be effective, they must meet on a regular basis.

Members of transdisciplinary teams have an enlarged information network and extended contacts who are capable of collaborating on a project from beginning to implementation. A transdisciplinary research community is a network of the minds of researchers from diverse disciplines.

As shown in Figure 4.3, collaboration, networking and education on a global scale are the keys to solving the complex problems and issues facing humankind in this century. The successful development of a network of global collaboration centers and institutes would provide a common sharing of knowledge and benefit everyone by significantly enhancing the ability to solve the unstructured problems the world is facing today.

4.5 Prevention through Design: Transdisciplinary Process

Paul Schulte, Director, Education and Information Division, NIOSH stated that the "Prevention through Design (PtD) process is a collaborative initiative that lies on the principle that the best way to prevent occupational injuries, illnesses, and fatalities is to anticipate and "design-out" or minimize hazards and risks when new equipment, processes, and business practices are developed," [29]. He also emphasized that the PtD process requires cross-disciplinary activities.

June M. Fisher reported that: "Implementing PtD will require the challenging transformative concept. Transformative changes are more broad and can lead to new forms and practices that guide us to safer and more productive environments. PtD, if viewed and practiced with broad vision, should further transformative changes that promote patient, worker, and environmental safety," [30]. A number of similarities exist between transformative and transdisciplinary concepts.

Schulte et al. clearly stated that: "An important element that should be included in the initiative is the need for global cooperation or harmonization. Due to the global influence on economies, workplaces, designs, and occupational safety and health, any major initiative, such as PtD, needs to have global input and support," [31]. Since PtD directly and indirectly involves with global issues, strong international collaborations and partnerships need to be established among stakeholders to have global input and support for PtD. This important observation reveals that PtD is a transnational activity.

The American workforce undergoes significant change because of immigration. Immigrants with job opportunities in the US usually have lower educational skill, greater poverty, and less income than the native-born population. In this situation, the difficulties of developing culturally integrated approaches to workplace safety and health

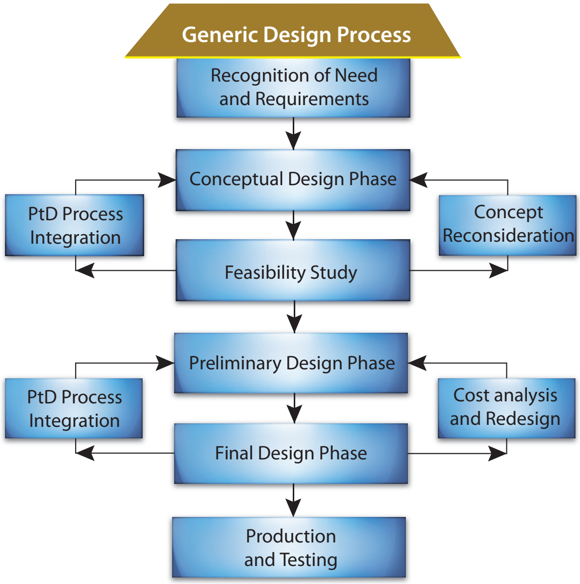

Figure 4.4 Generic Design Process (adapted from Ertas & Jones [32]).

should not be underestimated. As the world becomes increasingly multicultural, PtD process should consider synthesized transcultural theories, models, and research, to facilitate culturally harmonious and capable prevention and control of occupational injuries, illnesses, and fatalities.

Above discussions revel that PtD is a shared concept crossing many diverse disciplines including; agriculture, forestry and fishing; construction; health care and social assistance; manufacturing; mining; services; transportation, warehousing, and utilities; and wholesale and retail trade. A common research problem, which will be addressed by PtD associated with all the sectors from many different disciplines, is preventing and controlling occupational injuries, illnesses, and fatalities.

In summary, Prevention through Design is a transdisciplinary process that involves many transnational and transcultural issues.

4.6 PtD Consideration in the Design Process

The typical steps in the engineering design process are as shown in Figure 4.4. The generic design process shown in the figure is considered to be generally applicable to most design efforts, but the reader should recognize that individual projects often require variations, including the elimination of some steps.

Recognition of Need and Requirements

The design process begins with an identified need, which can be satisfied by the defined design requirements such as customer requirements, design requirements, and functional requirements. During this phase, the design team works closely with the customer to determine the requirements for the product. The requirements phase identifies the functionality, performance levels, and other characteristics which the product must satisfy in order to be acceptable to the customer. The requirements developed in this phase serve as a foundation for the remaining phases of the design process. It is important to note that establishment of the valid design requirements will be revisited and performed during the preliminary design phase.

Conceptual Design Phase

After the problem has been completely defined, during the concept development, viable solutions need to be identified from which the optimum approach can be selected. Assessment of the feasibility of the selected concept(s) is often accomplished as part of the conceptualization task on reasonably small projects but is usually a major element of the overall program on larger projects and sometimes it may take several years to complete. The goal 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 to. It is important to have research team members with broad experience and good judgment involved in the feasibility assessment phase of the design process. Team members 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 whom have a work ownership mentality.

Preliminary Phase

The preliminary design phase may also be known as architectural design. The preliminary 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 the preliminary design and, if more than one concept is involved, an assessment leading to the selection of the best overall solution must be performed. System-level and, to the extent possible, component level design requirements should be established during this phase of the process. The overall system configuration is defined during the preliminary design phase and a schematic, diagram, layout, drawing or other engineering documentation should be developed to provide early project configuration control. The overall system configuration is defined during this phase and a schematic, diagram, or 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 or transdisciplinary team integration and coordination during the detail design phase. The preparation of system testing and operational 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 design parameters and thus provide a valid basis for component design.

Detailed Design Phase

The goal of the detailed design phase is to develop a system of design drawings and specifications that completely provides a detailed specification for each component, thoroughly describing interfaces and functions provided by each component so that can be manufactured. At this design phase all the designers and researchers from diverse disciplines are actively involved in the synthesis/analysis process, resolving the system

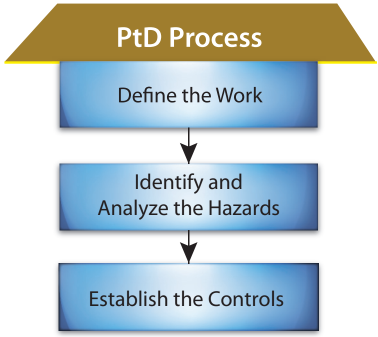

Figure 4.5 PtD Process.

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. The detailed design phase will serve as the basis for the production phase.

Production and Testing Phase

During this phase of the project, using the specifications created in the previous phases, the actual product is developed and manufactured. The final product will then be tested to ensure that it meets the requirements defined in the Requirements phase. As shown in Figure 4.4, Prevention through Design should be an important consideration throughout the design process.

4.6.1 PtD Process

The goal of this section is the integration of Prevention through Design (PtD) considerations into design activities during the conceptual, preliminary, and final design stages. Figure 4.5 shows a general process for Prevention through Design; namely, define the work related to product design then identify and evaluate potential safety hazard and injuries involved with the product, and finally control hazards that cannot be eliminated. This activity should be implemented throughout the entire design process as shown in Figure 4.4. PtD must be fully integrated in the early design process in the project. Namely, by the start of the concept development, a hazard analysis of alternatives to be considered and worker safety and health requirements for the design must be established. The main objective of PtD at the conceptual design phase is to evaluate alternative design concepts, to plan to protect workers safety and health from hazards and to provide a conservative safety design basis for a chosen concept to carry on into preliminary design. The conceptual design phase offers a key prospect for the safety and health hazard analysis to influence the product design.

Prevention through Design efforts during the preliminary design phase are planned to be incremental instead of a complete re-examination of the conceptual design. The hazard analysis will progress from a facility level analysis to a system level hazard analysis as design detail becomes available. When the hazard analysis is developed, the selection of controls, safety considerations, and classifications developed during the conceptual design phase must be revisited to make sure they are still appropriate. Decisions made during the preliminary design phase provide the basis for the approach to detailed design and production.

During the detailed design phase based on hazards and accident analysis of the final design, a final set of hazard controls will be developed. More detailed information on this subject can be found elsewhere [33].

The National Safety Council has recommended basic guidelines for designers to ensure acceptable safety and health for products and processes. The guidelines given below are broad, and as many as possible should be considered during product design and use [32]:

- Eliminate hazards by changing the design, the materials used, or the maintenance procedures.
- Control hazards by capturing, enclosing, or guarding at the source of the hazard.
- Train personnel to be cognizant of hazards and to follow safe procedures to avoid them.
- Provide instructions and warnings in documentation and post them in appropriate locations.
- Anticipate credible abuse and misuse and take appropriate action to minimize the consequences.
- Provide appropriate personal protective equipment and establish procedures to ensure that it is used as required.

4.7 Prevention through Design and Sustainability

The concepts of sustainability and PtD were identified as very congruent and able to co-exist [34]. Prevention through Design linked to sustainability in many ways. Sustainability refers to accepting a duty to seek harmony with other people and with nature. Sustainability is not just about the environment. It is sharing with each other and caring for the Earth.

Figure 4.6 shows Interconnectivity of environment, economy and society. As shown in this figure, sustainability is a multidimensional concept, involving environmental equity, economic equity and social equity. Therefore, an appropriate measurement framework should cover the economic, social and environmental dimensions of sustainable development. As shown in this figure, ethics are the building blocks of sustainable development and should be incorporated into design development strategy to ensure long-term sustainability.

For example, a sustainable building project must not result in undesirable harm to the environment during its construction and use. The building must also make economic wisdom such that, over the long term, the revenues will at least equal the expenses of constructing and operating it. Finally, the building must be socially acceptable such that the building will not cause any harm to any person or causes a group of people to experience injustice. What could be more unreasonable than to have workers construct a building that is not as safe to build as it could be? That is to say, isn't it fair to design a building to be safe as much as possible. A fair construction project is when the designers

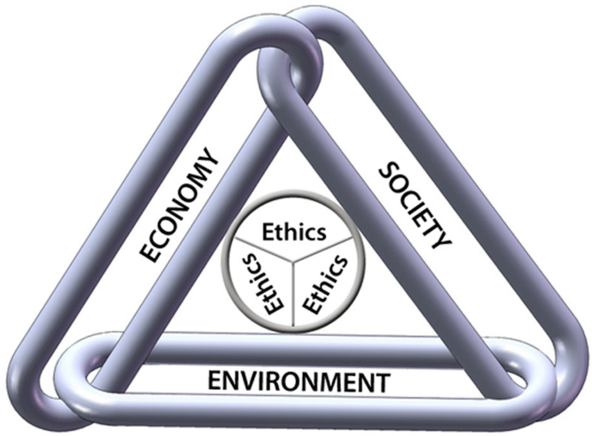

Figure 4.6 Sustainability and Interconnectivity of Environment, Economy and Society.

have made reasonable effort to "design out" or minimize hazards and risks early in the design process. Sustainable construction occurs when design contributes to safety [35].

4.7.1 Transdisciplinary Sustainable Develeopment

The engineering profession is being challenged with a new and forceful set of requirements, which appear about to happen: population growth, resource scarcity, and environmental change. For example, these include apparent changes to the atmosphere, hydrosphere, and biosphere resulting in major shifts from the environmental norms under which the artifacts of our civilization were originally designed. At one time, these aspects of the engineering design could be taken for granted, because of the obvious stability of the environment within a narrow, acceptable, and predictable range of change. Including the added interconnectivity and complexity of the environment, shifting requirements from environmental changes will not be easily addressed with methods descended from our industrial age.

Figure 4.7 shows one widely accepted concept of sustainable development—interconnectivity of environment, economy and society. The environment plays an important role in the well being of community development. It affects a broad range of social and economic variables which have a vital impact on the quality of community life, human health and safety. A dynamic environment contributes to a healthier society and a more strong economy. Similarly, the environment is itself affected by economic and social factors.

Traditional development was strongly related to economic growth, which provides economic prosperity for society members. During the early 1960s, the growing numbers of poor in developing countries resulted in considerable attempts to improve income distribution to the poor. As a result, the development paradigm changed towards equitable growth, where social (distributional) objectives, especially poverty alleviation, were accepted to be as important as economic efficiency. By the early 1980s, clear evidences proved that environmental degradation was a major barrier to development.

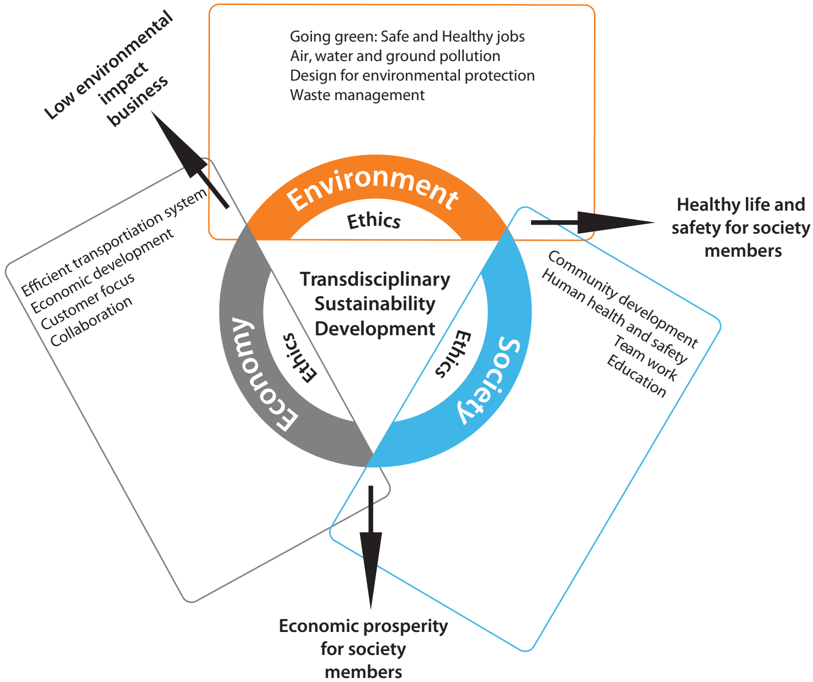

Figure 4.7 Transdisciplinary Sustainable Development.

Hence, protection of the environment became the third major element of sustainable development [36].

4.7.2 Contaminated Environment

> *Over increasingly large areas of the United States, spring now comes unheralded by the return of the birds, and the early mornings are strangely silent where once they were filled with the beauty of bird song.*
>
> **Rachel Carson**

Rachel Carson combined her interests in biology and writing as a government scientist with the Fish and Wildlife Service in Washington, D.C. Her book entitled "Silent Spring" is credited with inspiring much of the late 20th century's environmental concern as she documented the effect of pesticides on the ecology.

> *These sprays, dusts, and aerosols are now applied almost universally to farms, gardens, forests, and homes-nonselective chemicals that have the power to kill every insect, the "good" and the "bad," to still the song of birds and the leaping of fish in the streams, to coat the leaves with a deadly film, and to linger on in soil-all this though the intended target may be only a few weeds or insects. Can anyone*

> *believe it is possible to lay down such a barrage of poisons on the surface of the earth without making it unfit for all life? They should not be called "insecticides," but "biocides."*
>
> **Rachel Carson**

The condition of the environment and what can be done to protect it in the future ranks high among the concerns of Americans in the twenty-first century. The degradation in the environment that has occurred during the intervening years make it devastatingly clear that continued growth in population and economical development make the correction of past ecological misuse complex and expensive. Hazardous substances at uncontrolled hazardous waste sites including chemicals, pesticides, heavy metals and other toxic substances from industrial processes, refueling facilities and agriculture have been seeping into the ground and aquifer for many years. Scientists and engineers must begin to recognize the delicate nature of the environment in their endeavors and give it the priority it deserves.

Air Pollution

The quality of the layer of air that surrounds the earth has been degraded to the extent that warnings are issued in many cities when contamination levels reach the hazard zone. Joggers are warned about jogging at times of the day when smog levels are elevated, and many metropolitan areas in the world have enacted motor vehicle and other industrial emission controls in an effort to lower air pollution levels. In Mexico City, more than 21 million people live in an atmosphere so foggy that the sun is obscured, so poisonous that school is sometimes delayed until late morning when the air clears. Air pollution can be prevented by lowering emissions levels from motor vehicles, and changing to more environmentally friendly commercial products. Factories that produce hazardous air pollution should use "scrubbers" or other procedures on their smokestacks to eliminate contaminants before they enter the air outside the plant.

Groundwater Contamination

Groundwater is one of the most essential natural resources and degradation of its quality has a major effect on the wellbeing of people. The quality of groundwater reflects inputs from the atmosphere, from soil and water-rock reactions, as well as from contaminant sources such as mining, land clearance, agriculture, acid precipitation and industrial wastes. The fairly slow movement of water through the ground means that dwelling times in groundwater is generally orders of magnitude longer than in surface water. Groundwater is an important water resource that serves as a source of drinking water for the majority of the people living in the United States. Contamination from natural and human sources can affect the use of these waters. For example, spilling, leaking, improper disposal, or accidental and intentional application of chemicals on the land surface will result in overspill that contaminates close-by streams and lakes.

Strong competition among users such as agriculture, industry, and domestic sectors is driving the groundwater table lower. The quality of groundwater is getting severely affected because of the extensive pollution of surface water. The sustainability of groundwater utilization must be assessed from a transdisciplinary perspective, where hydrology, ecology, geomorphology, and climatology play an important role.

Environmental problems are essentially research and development challenges of a different order. These problems can be solved by scientists and engineers working together with political entities that can enact the necessary legislation, obtain the required international cooperation, and provide the necessary funding. The environment can no longer be considered an infinite reservoir in which chemical discharges, toxic material dumping, and harmful stack vapors can be deposited based on the lack of a measurable deleterious effect on the immediate surroundings.

Managing the environment is an international problem that cannot be based on monitoring and controlling at the local level only. Engineers and scientists must play a key role in providing the essential technology for understanding these global problems and in implementing workable solutions.

4.7.3 Making Green Job Safe: Integrating Occupational Safety &Health into Green Sustainability

In 2008 the world experienced the worst financial crisis of our generation, triggering the start of the most difficult recession since the Great Depression. The financial crisis has forced the policymakers to respond powerfully, creatively, and positively to severe financial crises: interest rates have been considerably reduced, stimulus package for green economy was signed, hundreds of billions of dollars have been provided to banking systems around the world. A stimulus package is planned to create or save up to 3.6 million jobs over the next two years, increase consumer spending, and stop the recession.

Barbier suggested that an investment of one percent of global Gross Domestic Product (GDP) over the next two years could provide the critical mass of green infrastructure needed to seed a significant greening of the global economy. "Green stimulus is well within the realm of the possible: at one percent of global GDP" [37, 38].

Although many elements of the green economy have value-added benefits for a global economy, we should retrain healthy consciousness of the potential hazards that workers face when performing Green jobs.

Schulte and Heidel stated that "There are benefits as well as challenges as we move to a green economy. Defined broadly, green jobs are jobs that help to improve the environment. These jobs also create opportunities to help battle a sagging economy and get people back to work. Yet, with the heightened attention on green jobs and environmental sustainability, it is important to make sure that worker safety and health are not overlooked. NIOSH and its partners are developing a framework to create awareness, provide guidance, and address occupational safety and health issues associated with green jobs and sustainability efforts, [39]."

Although many Green Job programs have the commendable goal of getting young workers into the workforce, it is known that these inexperienced new workers who could be the most at risk for job injuries. Moreover, in addition to these Green Job programs, stimulus package spending on infrastructure projects will also expose thousands of new workers to the myriad hazards encountered in the construction of bridges, highways, and public buildings. Hazards expected to be encountered in Green Jobs include [40]:

- Exposure to lead and asbestos in the course of energy efficiency retrofitting and weatherization in older buildings;
- Respiratory hazards from exposure to fiberglass and other materials in re-insulation projects;
- Exposure to biological hazards, such as molds, in fixing leaks;

- Crystalline silica exposure from fiber-cement materials, which may contain up to 50% silica;
- Ergonomic hazards from installation of large insulation panels;
- Fall hazards in the installation of heavy energy-efficient windows and solar panels and in the construction and maintenance of windmills (typically 265 feet tall);
- Electrical hazards encountered in the course of weatherization projects.

Green initiatives like recycling can have amazing successes. However, that doesn't automatically mean they are good for the earth, society or those working in 'green' jobs. For example more than 50 per cent of refined lead is now produced from recycled material. On the contrary, global lead production has increased considerably since 2003, placing a new generation at risk from an old and very toxic hazard.

As another example, Solar energy will play an essential role in meeting challenges such as human energy needs, address global warming, reduce U.S. dependence on energy imports, create "green jobs," and help revitalize the U.S. economy. However, as the solar PV sector expands, little attention is being paid to the possible environmental and health costs of that fast expansion. The most commonly used solar PV panels are based on materials and processes from the microelectronics industry and have the capability to create a huge new wave of electronic waste (e-waste) at the end of their useful lives. Recommendations to build a safe and sustainable solar energy industry include [41]:

- Reduce and eventually eliminate the use of toxic materials and develop environmentally sustainable practices,
- Ensure that solar PV manufacturers are responsible for the lifecycle impacts of their products through Extended,
- Producer Responsibility (EPR),
- Ensure proper testing of new and emerging materials and processes based on a precautionary approach,
- Expand recycling technology and design products for easy recycling,
- Promote high-quality "green jobs" that protect worker health and safety and provide a living wage throughout the global PV industry, including supply chains and end-of-life recycling,
- Protect community health and safety throughout the global PV industry, including supply chains and recycling.

4.7.4 Green During Construction

Green during the construction assures to the benefit of the surroundings community, workers and visitors on the site by reducing emissions, airborne pollution, and toxic gases like CO.

Green building development focuses on energy efficiency and using less toxic products from the perspective of future occupants of a building and also includes air quality issues such as, diesel exhaust generated by vehicles (which contains, nitrogen oxides, sulphur oxides and PAHs) in turn increases the risk of lung and perhaps bladder cancer. Also includes other health problems such as asthma and cardiovascular diseases. Similar problems can be expected from gasoline powered vehicles.

Dust is another issue in air quality. Dust consist of small solid particles created by a breakdown of fracture process, such as grinding, crushing or impact. Particles that are too large to stay airborne settle while others remain in the air indefinitely. General dust levels at considerably elevated concentrations may induce permanent changes to airways and loss of functional lung capacity.

Silica dust is accountable for a major American industrial disaster. Workers, number 300, die every year from silicosis, a chronic, disabling lung disease caused by the formation of nodules of scar tissue in the lungs. Hundreds more are disabled and between 3000 and 7000 new cases occur each year. Summarizing, high-risk work activities in construction are [38]:

- Chipping, drilling, crushing rock,
- Abrasive blasting,
- Sawing, drilling, grinding, concentrate and masonry and products containing silica,
- Demonstration of concrete/masonry,
- Removing paint and rust with power equipment,
- Dry sweeping of air blowing of concrete rock sand dust,
- Jack hammering on concrete, masonry and other surfaces.

Detail information on this subject can be found in reference [42]. Additional references on this subject are [43-69].

4.8 Conclusions

It should be obvious that the material presented in this module constitutes only cursory treatment of the very broad and important subject of prevention occupational injuries, illnesses, and fatalities to anticipate and "design-out" or minimize hazards and risks when new equipment, processes, and business practices are developed. However, some understanding of the relative roles of the PtD is important; thus a brief concept description of the transdisciplinary PtD process has been included in this report. By examples, it has been shown that the Prevention through Design is a transdisciplinary process that involves many transnational and transcultural issues.

In this chapter, it has been shown that PtD is a shared concept crossing many diverse disciplines including; agriculture, forestry and fishing; construction; health care and social assistance; manufacturing; mining; services; transportation, warehousing, and utilities; and wholesale and retail trade. A common research problem, which will be addressed by PtD associated with all the sectors from many different disciplines, is preventing and controlling occupational injuries, illnesses, and fatalities.

As the world becomes increasingly interconnected and multicultural, PtD process should consider synthesized tarnsdisciplinary, transcultural and transnational process models to facilitate culturally harmonious and capable prevention and control of occupational injuries, illnesses, and fatalities.

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5 From Transdisciplinarity to Transdisciplinary Research

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Abstract

Scholars promote various definitions and concepts of transdisciplinarity in the current dialogue. The concepts can be described as alternative combinations of four characteristic features of transdisciplinarity, namely (a) to relate to socially relevant issues, (b) to transcend and integrate disciplinary paradigms, (c) to do participatory research, and (d) to search for a unity of knowledge. The meaning of transdisciplinarity in the German-European environmental and sustainability research shifted during the last decades, making feature (c) – to do participatory research – its major component. Against that background, td-net has developed and promoted a concept of transdisciplinary research that includes additional features. Formulated from the perspective of transdisciplinary researchers, our concept endeavors to frame, analyze, and process a socially relevant issue in such a way that the research project (1) grasps the complexity of the issue, (2) takes the diverse perspectives on the issue into account, (3) links abstract and case-specific knowledge, and (4) develops knowledge and practices that promote what is perceived to be the common good.

5.1 Introduction

A person who is interested in transdisciplinarity and able to connect to the Internet will probably look for the meaning of the term in Wikipedia. The joy of finding an entry might be transient, however, since the first thing(s)he reads is a warning that the neutrality of the article on transdisciplinarity is disputed, that it may contain original research or unverifiable claims, and even that the article may require a general clean-up to meet Wikipedia's quality standards. This is not because nobody engages in writing and reviewing the article – as the revision history shows – but because a number of scholars write new paragraphs and revise or delete old ones. For example, I did not find any of td-net's attempts to define the term when I visited the page a year after td-net had made contributions to the definition. This radical reviewing process indicates that the meaning of transdisciplinarity is contested among different schools of thought. The schools of thought (including the one I represent) are to some extent trying to impress their view on transdisciplinarity as the right one to the others.

The contested meaning of transdisciplinarity is relatively ironic for a community of scholars who sees the openness to other viewpoints as the fundamental prerequisite for doing transdisciplinarity [1-4]. You might think: "That is no problem for me; I am open to other viewpoints; I tolerate them." The point of openness and open encounters is, however, not to accept that there are other perspectives but to understand one's own viewpoint as a relative (in contrary to an absolute) one amongst many others. Giri refers to the philosopher R. Sunder Rajan to give an impression of what is needed to comprehend the relativity of one's own position:

> "For Sunder Rajan, 'each perspective or point of view is such only as a member of a community of points of view' (...). The problem with modern disciplinary thinking is that it fails to realise that its claim to universality needs to be relativised by recognising the significance of other disciplines in gaining multiple perspectives about the world to which both one's as well as another's discipline contribute. In this context, for Sunder Rajan, 'each discipline must shed an illusory universality to gain a perspectival universality' (...) The task here is to realise that 'the possibility of other perspectives is not merely a contingent or incidental feature but is essential to the very form of a perspective; a perspective is because it is one among others"' [1]

Klein reminds us that transdisciplinary scholars – besides comprehending their relative perspective – have to work with multiple perspectives. Therefore they need "not only the general capacity to look at things from different perspectives, but also the skills of differentiating, comparing, contrasting, relating, clarifying, reconciling and synthesizing" [5][1]. In the following, I will attempt to implement those skills. First, I will give a structured overview of concepts of transdisciplinarity. Then a summary will be given of the history of the idea of transdisciplinarity in the German-European environmental and sustainability research. Against that background, the definition we have developed and promoted within td-net will be presented. Finally, three core challenges for transdisciplinary research, based on how we conceptualize it, will be outlined.

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[1]In the quotation Klein originally refers to interdisciplinary individuals. In the context of the quotation Klein understands transdisciplinarity in the sense of [6] as strong integration (by one person). Interdisciplinarity on the other hand is a collective approach and therefore close to the understanding of transdisciplinarity presented in the present paper [5].

5.2 Concepts of Transdisciplinarity

The fact that the meaning of transdisciplinarity is contested – at least in the current Wikipedia-debate – does not imply that "anything goes." Rather, an analysis of current definitions of transdisciplinarity reveals two common patterns [4]. The first is that definitions of transdisciplinarity usually propose a progression from multidisciplinarity through interdisciplinary to transdisciplinarity. It is a progression because every "x-disciplinarity" goes further than the previous one in a specific aspect[2]. Jantsch [6] sees the progression in the degree of coordination within the whole education and innovation system. In transdisciplinarity, the whole system is oriented around an overall purpose like "progress" or "ecological balance." For Rosenfield [7], the progression lies in the shared conceptual framework. Interdisciplinarity means that researchers from different disciplines use their respective methods, techniques, and skills to address a common issue. Transdisciplinarity encourages representatives of different disciplines "to transcend their separate conceptual, theoretical, and methodological orientations in order to develop a shared approach to the research, building on a common conceptual framework." Lawrence sees the progression in the bodies of knowledge and societal groups involved: "Interdisciplinarity can be considered as the mixing together of disciplines, whereas transdisciplinarity implies a fusion of disciplinary knowledge with the know-how of lay-people" [8]. Hence, while the definitions share the idea of progression from multi- to inter- and transdisciplinarity, the definitions differ in the main feature of this progress.

The second common pattern the analysis of definitions revealed is that only a limited number of features are used to characterize transdisciplinarity. The features are (1) the focus on socially relevant issues, (2) transcending and integrating disciplinary paradigms, (3) doing participatory research, and (4) the search for a unity of knowledge beyond disciplines. In accordance with how they weigh these characteristics, the definitions can roughly be classified into three groups (see Table 5.1).

In concept A, research becomes transdisciplinarity by transcending and integrating disciplinary paradigms in order to address socially (as opposed to academically) relevant issues. Transdisciplinary research is needed since the ongoing process of specialization of scientific knowledge production is driven by inner-scientific and disciplinary concerns, increasingly veering away from social problems and concerns. In a nutshell, Brewer puts this as "[t]he world has problems, but universities have departments" [9]. The academic knowledge production, organized from a disciplinary perspective, has to be re-organized and re-assessed from the perspective of the socially relevant issue. Scholars representing concept A are Rosenfield [7], Jantsch [6] or Mittelstraß [10].

According to concept B, transdisciplinarity means to expand concept A by including non-academic actors (i.e. participatory research). By including non-academic actors, a discussion on knowledge production that was very influential in Europe is referred to. Gibbons et al. [11] and Nowotny et al. [12] identified a new mode of knowledge production, so called Mode 2. Mode 2 is supplementing the traditional linear model, within which "science proposes, society disposes" [13]. Mode 2-knowledge is produced in the

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[2]*This progress might be part of the rhetoric of definition rather than a factual necessity: "There is no inevitable progression form 'multidisciplinarity' through 'interdisciplinarity' to 'transdisciplinarity.'" [5]*

Table 5.1 Three Concepts of Transdisciplinarity (A, B, C) as Combinations of Four Features (based on [4]).

Transdisciplinarity according to concept / Features of transdisciplinarity	A	B	C
Relating to socially relevant issues	■	■	■
Transcending and integrating disciplinary paradigms	■	■	■
Participatory research		■	
Searching for a unity of knowledge			■

context of the application of knowledge (in contrary to the academic ivory tower). The process of knowledge production includes stakeholders from science, civil society, and the private and public sector. To my understanding, for example Kötter [14], Scholz [15], Lawrence [8], and Mobjörk [16] are representatives of concept B of transdisciplinarity. The feature of participatory research is commonly not attributed to transdisciplinarity in the American context. Hence, Stokols [3] designates concept B of transdisciplinarity for the American context as "transdisciplinary action research." "Action research" stands for a participatory approach.

According to concept C, research becomes transdisciplinary by adding the search for a unity of knowledge to concept A. The search for a unity of knowledge is not an end in itself. As with concept A, the overall aim is to reorganize the academic knowledge in order to make it useful for addressing socially relevant issues. In contrast to concept A, however, the knowledge is not re-organized and re-assessed in a pragmatic and eclectic way but by developing a general viewpoint or perspective beyond all disciplines. It is on the basis of such a fundamental viewpoint of knowledge beyond all disciplines that the socially relevant issues will be structured, analyzed, and processed in a second step. Nicolescu [17] and Ramadier [18] represent concept C of transdisciplinarity.

5.3 Transdisciplinarity as a Concept in Flux[3]

On the one hand, the concepts of transdisciplinarity promoted by individual scholars or schools of thought are rather stable. On the other hand, if you track the meaning of transdisciplinarity in a specific context – for example in the German-European environmental and sustainability research in the last decades – the meaning of transdisciplinarity may

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[3]*This chapter draws upon chapter 11.2.1 of Bunders et al. [19]*

shift. Transdisciplinarity becomes a concept in flux. The four features and the three concepts of transdisciplinarity (Table 5.1) are instrumental in tracing such a shifting meaning.

In Switzerland, transdisciplinarity was promoted by two initiatives of environmental research in the early 1990s: The scientific journal GAIA - Ecological Perspectives for Science and Society launched in 1991 and the "Swiss Priority Program Environment" initiated in 1992. The German philosopher Mittelstraß introduced concept A of transdisciplinarity in the editorial of the fifth issue of the first volume of GAIA:

> "[T]ransdisciplinarity refers to knowledge or research that frees itself of its specialised or disciplinary boundaries, that defines and solves its problems independently of disciplines, relating these problems to extra-scientific developments" [20, translated by Anne B. Zimmermann].

Since then, time and again, papers are published addressing transdisciplinarity as a concept or presenting transdisciplinary research in the field of environmental issues or sustainable development. Within GAIA, concept A of transdisciplinarity persists, as can be seen from GAIA's homepage: "[e]nvironmental problems cannot be solved by one academic discipline. The complex natures of these problems require cooperation across disciplinary boundaries."[4] The second promoter of transdisciplinarity was the "Swiss Priority Program Environment" (SPPE, 1992-2000), at that time the largest founding opportunity for environmental research in Switzerland with an overall budget of around 100 Mio USD. It was SPPE's program management that strongly promoted transdisciplinarity. SPPE was, on the part of the government, expected to help solve environmental problems through the program's research. The program managers considered transdisciplinarity instrumental to meet this expectation [21]. Toward the end of SPPE, the program's steering committee mandated two researchers interested in the management of inter- and transdisciplinary processes to elaborate criteria for evaluating inter- and transdisciplinary research [22]. To develop criteria, they had to define what should be evaluated, i.e. transdisciplinarity. This definition shifted the meaning toward concept B of transdisciplinarity, stressing participatory research.

> "Transdisciplinary research, in turn, here denotes interdisciplinary cooperation, involving not only scientists but also practitioners from beyond the realm of science (e.g., the users) in the research work." [22]

One reason for the shift was that SPPE was expected to contribute to social change with regard to environmental issues and including the "users" and "practitioners" seemed instrumental for that purpose. This shift toward concept B gained momentum at the program's closing conference, "Transdisciplinarity: Joint Problem Solving among Science, Technology and Society" [23]. Gibbons and Nowotny gave a keynote lecture on Mode 2 knowledge production, which takes place in the context of application, joins scientists and representatives of other societal sectors in the "agora," and provides "socially robust knowledge" [23].

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[4]*http://www.oekom.de/etc/gaia, retrieved on November 2nd 2010.*

A number of European research programs on environmental and sustainability issues – like the Austrian programs "proVISION for nature and society" (2004-present) and "Transdisciplinary forms of research" (TRAFO, 2004-2007) and the German program "Social-Ecological Research" (SÖF, 1999-present) – referred to and further developed SPPE's concept B of transdisciplinary research. In the early years of the new millennium, concept B - and specifically the feature of participatory research - gained still more momentum. In some of the research programs, transdisciplinarity even became synonymous with participatory research. Accordingly, one of the research programs states: "Transdisciplinary research […] aims at participation of various groups of civil society, who are potential users of the research results, in the research process."[5]

5.4 Transdisciplinarity as a Practice of Research

In terms of transdisciplinarity as a concept in flux, concept B of transdisciplinarity – stressing participatory research as its key feature – dominated when td-net started working for the Swiss Academies of Arts and Sciences in 2003[6]. Td-net was carrying on the work of sagufnet, a network for transdisciplinary research of the Swiss Academic Society for Environmental Research and Ecology (SAGUF) launched at the transdisciplinarity conference in 2000 [23]. The mission of td-net is to strengthen transdisciplinary research in all thematic fields, be it in research on peace, public health, sustainability, migration, and cultural diversity or on any other socially relevant issue. Amongst other activities, td-net organizes conferences to enable cross-field learning and publishes case studies and methodical and theoretical considerations on transdisciplinary research [24, 25].

The primary aim of td-net is to develop transdisciplinarity in the academic sector as a form of research. Our perspective on transdisciplinarity is that of a researcher asking him- or herself how to do transdisciplinary research. This does not imply that we see transdisciplinarity as a purely academic endeavor. It would be interesting to learn about the challenges of a transdisciplinary project as seen from the perspective of an actor of civil society or the private or public sector. And some might argue that it would be much more relevant to look at transdisciplinarity from a non-academic actor's perspective. The decision of td-net was, however, to be primarily a network supporting researchers who engage in transdisciplinary endeavors.

This viewpoint implies a specific way of "defining" transdisciplinarity. It is not defined from the position of a detached observer who analyzes definitions of transdisciplinarity for its underlying specific features as in Table 1. The definition, rather, has to support researchers facing, for example, the issue of migration from Africa to Italy or the sustainable development of a touristic valley of the Swiss Alps. The question of researchers in such a situation is:

"What do I have to consider in my research to make a relevant contribution to the societal handling of the issue?" This leads us back to the purposes of integrating disciplinary paradigms, including social actors and developing overarching viewpoints, to develop a comprehensive understanding of the issue and to provide practical and useful

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[5] *http://www.trafo-research.at, mission statement, retrieved on November 2nd 2010.*
[6] *www.transdisciplinarity.ch*

knowledge. Td-net's understanding of transdisciplinary research was developed against the background of the German-European environmental and sustainability research depicted above. This is why we took the aim of addressing a socially relevant issue as a starting point, in line with Wickson et al. who identified the problem focus – "the explicit intent to solve problems" [26] – as the first of three key characteristics of transdisciplinarity. In order to be relevant for problem handling, transdisciplinary researchers have to frame, analyze, and process an issue in such a manner that

(1) they grasp the complexity of the issue,
(2) they take the diverse perspectives on the issue into account,
(3) they link abstract and case-specific knowledge, and
(4) they develop knowledge and practices that promote what is perceived to be the common good [4].

From this perspective, three of the features of transdisciplinarity identified above – transcending and integrating disciplinary paradigms, participatory research, and searching for a unity of knowledge – are means that can be used to achieve the requirements (1)-(4). The requirements (1)-(3) are basics of the rationale for transdisciplinarity as a way to address social issues [27]. On the other hand, the promotion of the common good – or, more generally speaking, the evaluative component of transdisciplinary research – is rarely stated explicitly in definitions of transdisciplinarity even though an evaluative component is inevitable in order to know what an improvement of the current situation might look like. "The common good" here serves as a placeholder for underlying value systems in different thematic fields: "Peace" in peace research, "public health and well being" in public health research, "equality" in gender or cultural diversity research, or "sustainability" in research for sustainable development. Requirement (4) does not imply that one of the researchers (e.g. an ethician) or any another participant (e.g. a pastor) knows what the common good means in the project's specific context. Rather, one of the challenges for transdisciplinary researchers is to clarify underlying value systems by jointly developing the concrete meaning of, for example, sustainable development for the research project's specific context [28].

5.5 Consequences for the Practice of Transdisciplinary Research

Requirements (1)-(4) result in a different overall design of the research process compared to a disciplinary research project. Three new challenges the researchers have to address are problem framing, integration, and bringing results to fruition (usually termed "implementation"). These challenges and ways to address them are further elaborated in [24] and in [4]. They are briefly outlined in the following section.

Problem framing

In a disciplinary research project, the problem is framed by disciplinary standards, such as the state of knowledge, methods, and theories (i.e. the disciplinary paradigm in Kuhn's terminology) [29]. In transdisciplinary research, researchers from different disciplines as well as actors form civil society and the private and public sectors are involved and perceive the issue from different perspectives. What is a pressing problem for one of them might not even be seen as a problem for somebody else.

The requirements of comprehending the issue in its complexity as well as taking into account the diverse perspectives call for a specific stage of collective problem framing. This stage is not common to recent research: funding agencies usually do not fund a stage of problem framing, and researchers do not apply for it. The few existing methods and approaches to problem framing often have an explorative character. Among those are the joint formulation of working hypotheses [30], a reformulation of the issue from the perspective of those who act [31], or methods that explore the different problem views by qualitative analysis [32-34] and interrelate them by means of dialogue methods.

Integration

Integration refers to the process of combining and reconciling research- and experience-based knowledge and perspectives of the academic and non-academic participants. It is not like composing the pieces of a puzzle since the perspectives might not add to each other. This is because they are founded in different value systems and different ideas about what relevant knowledge is, how it can be gained, or what role science should play in social change [35]. With regard to complexity, the aim of integration is to achieve a more comprehensive and, with regard to power relations, a more balanced understanding of an issue and ways to handle it. Integration is seen as a core challenge of transdisciplinary research [36-40]. It may be more or less targeted to an overall synthesis. In a minor sense, integration refers to the mutual exchange of ideas and learning about different values and standpoints. Primarily, though, integration means jointly developing a shared theoretical understanding of the issue at stake. The task of integration cuts across the transdisciplinary research process, from problem framing through problem analysis to bringing results to fruition. Recently, scholars make first attempts to distinguish alternative approaches to integration [37, 40] and to develop and describe tools for [41] and methods of [42] integration.

Bringing results to fruition

Transdisciplinary research does not end with providing tailored knowledge to actors in civil society, the private sector, and public agencies. It calls for further engagement beyond making the results known and informing multipliers and key players. Referring to the terminology of Groß et al. [43], the stage of implementation, or to jointly work with non-academic actors in a transdisciplinary research project, can be seen as a real-word experiment, as an "experimental implementation" [44]. This means that implementation should be seen as an intervention in a social system and effects should be carefully observed with particular attention to surprises (unexpected effects). Surprises indicate that the assumptions, models, and explanations underlying the transdisciplinary research should be revised. New interventions can then be planned and conducted. To see the implementation as a real-world experiment is a means of reflection or getting reflective. This implies that the intended effect of a transdisciplinary research project becomes a subject of analysis and further development, too. This usually requires a long-term perspective of projects and project partnerships (up to several decades) as well as a recursive planning of the transdisciplinary research process, going back and forth between implementing, analyzing, developing new solutions, and perhaps re-framing the problem. Kiteme and Wiesmann [45] as well as Schelling et al. [46] provide exemplary case studies of such recursive, long-term transdisciplinary research processes.

5.6 Conclusion

In the world of Wikipedia, transdisciplinarity is a concept in flux. The meaning is contested and the debate open and not yet ready for closure. In an optimistic reading, this is an expression of an ongoing, lively debate among scholars, in a pessimistic reading, of a dispute about the right definition. Referring to requirement (2) of our understanding of transdisciplinary research – to respect the diversity of perspectives – I believe that we will not come up with a unifying definition but with a structured plurality of definitions. The present analysis suggests a structuring of definitions by clarifying their perspective – here researchers who conduct transdisciplinary projects, here the German-European environmental and sustainability research. If we go in that direction, we will further explore the meaning of Sunder Rajan's saying that "a perspective is because it is one among others" [1].

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6 A Knowledge Component Framework for Enhancing Transdisciplinary Knowledge Assimilation

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Abstract

Research shows that generating new knowledge is accomplished via natural human means: mental insights, scientific inquiry process, sensing, actions, and experiences, while context is information which characterizes the knowledge and gives it meaning. Transdisciplinary research literature clearly argues for development of strategies that transcend any one given discipline and that enhance research collaboration. A new framework, coined Recombinant kNowledge Assimilation (RNA), was constructed in this research. The framework was successfully applied recursively to abstracts from research manuscripts. Using RNA, disciplinary and transdisciplinary knowledge components and context were systematically discovered creating a mechanism to interact with dynamically changing research knowledge and assimilating it to form explicit new knowledge while simultaneously retaining the causal pedigree captured during manuscript processing.

6.1 Introduction

6.1.1 Definations

Six important terms consistently used within this paper are defined as follows.

Recombinant: Establishing new relationships between any two or more pieces of information to create new knowledge

Knowledge: A relationship between any two or more pieces of information which has crossed the importance threshold to become established in the mind of the stakeholder

Context: Information which characterizes knowledge and gives it meaning

Recursion: Repeated application of functions on information and knowledge to create new knowledge; continuous input

Knowledge Components: Discrete logical groupings of various granularity of information content, upon which effort of thought has been expended to understand
Transdisciplinary Research: Collaborative research within many disparate disciplines working together to develop strategies and implements to dissolve the hardened discipline silos of knowledge to solve common problems that transcend any one discipline

6.1.2 Knowledge

Nonaka and Takeuchi [1], when describing how Japanese companies innovate as knowledge creating organizations, described two types of knowledge: tacit and explicit. Tacit knowledge is personal and context-specific. Explicit knowledge is knowledge codified in books, journals and other documents for transmittal. Additionally, Nonaka [2] prescribed how dynamic organizational creation of knowledge needs to be strategically collected, understood, and managed across the entire company's organizational structure as intellectual capital. Knowledge theorist Polanyi and Sen [3], in describing what he called the "Tacit Dimension," used the idea of tacit knowledge to solve Plato's "Meno's paradox," that deals with the view that the search for knowledge is absurd, since you either already know it or you don't know what you are looking for, whereby you can not expect to find it. The author argued that if tacit knowledge was a part of knowledge then "we do know what to look for and we also have an idea of what else we want to know," therefore personal and context-specific knowledge must be included in the formalization of all knowledge. Renowned fuzzy logic theorist Zadeh [4], described tacit knowledge as world knowledge that humans retain from experiences and education, and concluded that current search engines with their remarkable capabilities do not have the capability of deduction, that is the capability to synthesize answers from bodies of information which reside in various parts of a knowledge base. More specifically Zadeh, describes fuzzy logic as a formalization of human capabilities: the capability to converse, reason and make rational decisions in an environment of imprecision, uncertainty, and incompleteness of information. Tanik and Ertas [5] described, knowledge as generated through mental insights and the scientific inquiry process, usually stored in written form, assimilated through mental efforts, and disseminated through teachings and exposure in the context of a disciplinary framework. Kim et al. [6] used a case study to develop an organizational knowledge structure for industrial manufacturing. Specifically, a methodology was developed for capturing and representing organizational knowledge as a six-step procedure, which ranged from defining organizational knowledge to creation of a knowledge map for validation. The defined knowledge was extracted from the process as three types: prerequisite knowledge before process execution, used knowledge during execution, and produced knowledge after execution. Spender [7] stated that universal knowledge true at all times is the highest grade that knowledge can attain. Gruber [8] when describing social knowledge systems on the web and their relationship to semantic science and services, defined knowledge as "collective knowledge" that is collaborated upon. When describing how science integrates with information theory, Brillouin [9] defined knowledge as resulting from a certain amount of thinking and distinct from information which had no value, was the "result of choice," and was the raw material consisting of a mere collection of data. Additionally, Brillouin concluded that a hundred random sentences from a newspaper, or a line of Shakespeare, or even a theorem of Einstein have exactly the same information value. Lastly, Engelbart [10] when describing the needs of the optimal workplace, depicted what he called the "knowledge workshop," where a knowledge worker performed work, and that knowledge represented integrated domains of knowledge which were natural and specialized [11].

6.1.3 Context

Dourish [12] expressed that the scientific community has debated definitions of context and it's uses for many years. He discussed two notions of context, technical, for conceptualizing human action relationship between the action and the system, and social science, and reported that "ideas need to be understood in the intellectual frames that give them meaning." Hence, he described features of the environment where activity takes place [13]. Torralba [14] derived context based object recognition from real-world from scenes, described that one form of performing the task was to define the 'context' of an object in a scene was in terms of other previously recognized objects and concluded, that there exists a strong relationship between the environment and the objects found within, and that increased evidence exists of early human perception of contextual information. Dey [15] presented a Context Toolkit architecture that supported the building of more optimal context-aware applications, because, he argued, that context was a poorly used resource of information in computing environments and that context was information which must be used to characterize the collection of states or as he called it the "situation abstraction" of a person, place or object relevant to the interaction between a user and the application. When describing a conceptual framework for context–aware systems, Coutaz et al. [16] concluded that context informs recognition and mapping by providing a structured, unified view of the world in which a system operates. The authors provided a framework with an ontological foundation, an architectural foundation, and an approach to adaptation, which they professed, all scale alongside the richness of the environment. Graham and Kjeldskov [17] concluded that context was critical in the understanding and development of information systems. Winograd [18] noted that intention could only be determined through inferences based on context. Hong and Landay [19] described context as knowing the answers to the "W" questions (e.g. Where are the movie theaters?). Similarly, Howard and Qusibaty [20] described context for decision making using the interrogatory 5WH model (who, what, when, where, why and how). Lastly, Ejigu et al. [21] presented a collaborative context aware service platform, based upon a developed hybrid context management model. The goal was to sense context during execution along with internal state and user interactions using context as a function of collecting, organizing, storing, presenting and representing hierarchies, relations, axioms and metadata.

6.1.4 Transdisciplinary Research

Rosenfield [22] argued for transdisciplinary research as a process where members of different fields work together over time to develop novel concepts and frameworks with potential to produce new approaches which transcend inter- and multidisciplinary research. Ertas et al. [23] described transdisciplinary research and education in context of addressing large-scale, modern engineering systems to prepare engineers, designers, and researchers of the future. Described are three critical attributes, namely, clarification of theoretical issues involved in crossing disciplinary boundaries, development of a more comprehensive understanding of large-scale problems, and integration of concepts and methods from other disciplines which share similar levels of analysis. Pohl [24] stated that an aim of transdisciplinary research is to get natural and social scientists to collaborate, so as to achieve an integrated view subjects that go beyond the viewpoints offered by any one particular discipline. Stokols et al. [25] described a two decade surge of interest and investment in transdisciplinary research and described a framework for understanding and evaluating transdisciplinary research. Finally, Nicolescu [26] described transdisciplinary research as a "transdisciplinary model of nature which must integrate all new knowledge of emergent characteristics of the universe." Additionally, he concluded that there are three major aspects of nature that follow the transdisciplinary model of reality: Objective Nature, the natural properties of the transdisciplinary object, Subjective Nature, the natural properties of the transdisciplinary subject, and Trans-nature, the similarity in nature between the object and subject.

6.1.5 Organization of Knowledge and Context

In 1957 Newell et al. [27] and Simon [28] together developed models of human mental processes and produced General Problem Solver (GPS) to perform "means-end analysis" to solve problems by successively reducing the difference between a present condition and the end goal. GPS organized knowledge into symbolic objects and related contextual information which were systematically stored and compared. Almost a decade later Sternberg [29] described a now well-known paradigm called the Sternberg Paradigm where, observations of participants were taken during experiments to determine how quickly the participants could compare and respond with answers based upon the size and level of understanding of their knowledge organized into numerical memory sets. Sternberg Paradigm is known for (1) organizing knowledge and modifying context while using a common process for describing the nature of human information processing and (2) human adaptation based upon changes in context. Similarly, Rowley and Hartley [30] described the development of knowledge as the organization and processing required to convey understanding, accumulated learning, and experience. Object Oriented Design (OOD), as defined by Booch [31] and Rumbaugh et al. [32], organized knowledge and attributes describing details of objects in the form of general objects of information, using a bottom-up approach, iteratively building its components and attributes through a series of decisions. Booch's more generalized design decisions occurred via five basic phases which he described as part of the macro processes of OOD: Conceptualization which established the core requirements, analysis which developed the desired behavior via a model, design which included various architectural artifacts, and evolution which was the core component responsible for iterative bottom-up development, and lastly maintenance which managed the spiral delivery of functional capability. The details Booch described in the micro processes of his definition of OOD were the critical design mechanisms which fleshed out design details to take the conceptualization phase requirements to an implementable solution. The micro process components were, namely, identify and classify the abstraction of objects, identify the semantic representations of the objects and classes which define them, identify via specialized OOD notation the relationships between the objects, and finally the specification of the interfaces, the physical implementation of the defined classes and run-time objects. More recently, Gruber [8] described the collection of knowledge and context on the web as "collective intelligence." Gruber based his opinion on Elgelbart's [11] principle which stated the need for creating combined human-machine interactive systems which can boost the collective intelligence of organizations and society via automated harvesting of collected knowledge for collective learning. Specifically, Gruber added that true collective intelligence can emerge if aggregated information from the people is recombined to create new knowledge. Van Ittersum et al. [33] organized knowledge and context as individual stand-alone knowledge components in agricultural systems which can be linked using a software infrastructure. Finally, Ejigu et al. [21] defined the organization of knowledge and context as a process of collection and storage. Their work proposed what they described as a neighborhood based context-aware service platform which was user collaborative in nature, that managed the reusability of context resources and reasoning axioms, and shared computational resources among multiple devices in the neighborhood space. They used a semantic ontology based hybrid model known as EH-RAM as the core data source from which they systematically collected and stored information content, reasoned upon with their reasoning engine and then disseminated via their interface manager to the user. The main components of EHRAM context model were used to model the information content sources as a set of hierarchies (H), set of entities (E), set of entity relations (Re), set of attribute relations (Ra), set of axioms (A) and set of metadata (M). Hence, the information data source content was collected and stored as the EHRAM layered context representation structure.

6.1.6 Presentation of Knowledge and Context

Trochim [34] described Concept Maps to present knowledge and context as structured conceptualization used by groups to collaborate thoughts and ideas. Described was the typical case in which concept maps are developed via six detailed steps: the "Preparation," which included the selection of participants and development of the focus for conceptualizing the end goal, such as brainstorming sessions and developing metrics, (e.g. rating the focus), the "Generation" of specific statements which reflected the overarching conceptualization, the "Structuring" of statements which described how the statements are related to one another, the "Representation" of statements in the form of a presented visual concept map, which used multidimensional scaling [35] to place the statements in similar proximity to one another and cluster analysis [36] which determined how to organize the presentation into logical groups which made sense, the "Interpretation" of maps which was an exercise in consensus building once the representation had been created; and finally the "Utilization" of maps which was described as a process by which the groups within the process collectively determine how the maps might be used in planning or evaluation of related efforts. Stated was that concept mapping encouraged groups to stay on task which then resulted relatively quickly into an interpretable conceptual framework. It also expressed the framework entirely in the language of the participants and finally yielded a graphic or pictorial product. The product simultaneously presented all major ideas and their interrelationships and often improved group or organizational cohesiveness and morale. Graph theory, was shown to be used within many disciplines as an approach to visually and mathematically present knowledge and context relationships, [37]. In Software Engineering, many traditional tools exist: Entity Relationship Diagrams (ERD), Sequence Diagrams (SD), and State Transition Diagrams (STD) which each present different knowledge and context about database, and systems [38]. More recently, Universal Modeling Language (UML) [39] and semantic and ontology based software development tools, as well as, descriptive Resource Description Framework (RDF) language [40], and Web Ontology Language (OWL) [41] were used extensively to create, store, and present knowledge and context, using shapes, lines, and text as relationships between objects of information. However, Ejigu et al. [21] argued that ontology tools were only good at statically presenting knowledge of a domain and that they were not designed for scalable capturing and processing dynamic information in constantly changing environments.

6.1.7 Representation of Knowledge and Context

Dourish [13] concluded that representation of knowledge and context is an ethno methodological problem of encoding and representing social motivation behind action and that translating ideas between different intellectual domains can be exceptionally valuable and unexpectedly difficult. One reason is that ideas need to be understood within the intellectual frames that give them their meaning, and therefore need to be sensitive to the problems of translation between the frames of reference. Additionally, he describes four assumptions which represent context in systems, first, context as a form of information which can be encoded and represented in software systems just as other information content, second, context is delineable and therefore for a set of requirements, context can be defined as activities that an application supports and it can be done in advance, third, context is stable and hence can vary representation from one software application to another but does not vary from instance to instance of an event, it was specific to an activity or an event. Lastly, Dourish concluded, that most importantly context is separable from the action or activity, since context described the features of the environment where the activity takes place, separate from the activity itself. Dourish proposed an interactional model of context, where the central concern with representing context was with the questions, ‘‘how and why” during interactions, do people achieve and maintain a mutual understanding of the context for actions. Polyn and Kahana [42] described that cognitive theories suggest that recall of a known item representation is driven by an internally maintained context representation. They described how neural investigations had shown that the recall of an item represented in the mind is driven by an internally maintained context representation that integrated information with a time scale. Howard and Kahana [43] stated that by linking knowledge items and context representations in memory, one could accomplish two useful functions. First, one could determine whether a specific item occurred in a specific list (episodic recognition). Second, one could use a state of context to cue item representations for recall (episodic recall). Konstantinou et al. [44] concluded that a common knowledge representation formalism ought to allow inference extraction, and proposed “Relational.OWL,” based tool to automate structural representation of knowledge ontology to database mapping. Additionally, Ejigu et al. [21] made the argument that context was missing from systems and is in the “head” of the user, and proposes an ontology based structure using RDF representation of knowledge and context with metadata attributes. Zouaq et al. [45], concluded that Natural Language Processing (NLP) enabled structured representations of documents. They proposed a knowledge puzzle approach using ontology based learning objects, semantic maps, and grammatical maps, which represented structure of context on the basis of using text relations. Similar to Trochim [34], Novak and Canas [46] described the structure of concept maps as a mechanism for structural representation of knowledge and context.

6.1.8 Frameworks for Knowledge and/or Context

Liao et al. [47] represented context in a knowledge management framework comprising processes, collection, preprocessing, integration, modeling and representation, enabling transition from data, information and knowledge to new knowledge. The authors also indicated that newly generated knowledge was stored in a context knowledge base and used by a rule-based context knowledge-matching engine to support decision-making activities. Gupta and Govindarajan [48] defined a theoretical knowledge framework and measured the collected increase of knowledge flow out of multinational corporations based upon "knowledge stock" (e.g., the value placed upon the source of knowledge). Pinto [49] developed a conceptual and methodological framework to represent the quality of knowledge found in abstracts. Suh [50] concluded that collaborative frameworks do not provide the contents which go in them, therefore, content was discipline specific, required subject matter experts, and clear decision making criteria. Additionally, Suh noted was that processes promoting positive collaboration and negotiation were required to achieve the best knowledge available, and were characterized by process variables and part of what he defined as the Process Domain. Finally, Ejigu et al. [21] created a framework for knowledge and context which collected and stored knowledge as well as decisions in a knowledge repository that corresponded to a specific context instance. Subsequently, the framework evaluated the knowledge and context via a reasoning engine.

6.2 Motivation

Ertas et al. [23] described a need to address complexities whereby important knowledge within one discipline can be systematically discovered, and recombined into other disciplines to solve common problems and for enhancing and augmenting other fields of study. Stokols [51] noted that there was a need to achieve a more complete understanding of prior research collaborations and sustain future ones and their content, and Fry [52] described the importance of integration between subject disciplines, Llinas et al. [53] described a challenge, to harness actionable knowledge from complex interrelated cross-domain data. Konstantinou et al. [44] concluded that a lack of a generally accepted, unified, and common knowledge representation impedes data exchange, interoperability and collaboration. Dourish [13] concluded that, presentation of context is extremely problematic since context is continually renegotiated and redefined. Nicolescu [26] concluded that a transdisciplinary model must integrate the emerging characteristics of the physical universe and that a need exists to use tools in physics describing reality with mathematical formalization. Torralba [14] indicated a need to represent the strong relationships which exist in the environment with the objects found within. Finally, motivation was drawn from a need as described by Ejigu et al. [21] for providing collection, organization, storage, presentation, and representation of knowledge and context, together which addressed the significant challenge of quality context and by Liao et al. [47], who indicated the need for representing context in a knowledge management framework for enabling transition from data, information, and knowledge to new knowledge.

Therefore, the goal of this research was to develop implements for effective transdisciplinary research, and to develop mechanisms to dissolve the knowledge barrier between hardened discipline silos of knowledge. The literature clearly argues for strategies, methodologies, tools, frameworks to further the development and quality of transdisciplinary thought and practice. This research aimed to answer the question, "Can a framework be developed to enhance transdisciplinary research knowledge?" This question was focused intentionally and exclusively on the research and development of a framework. This research proposed the exploration of the framework's application to journal abstracts rich in discipline specific research information content for enhancing the meaning and/or relevance of discovered knowledge and context.

6.3 Scope and Methods

The scope of work involved the development of three specific aims: the organization of knowledge and context, the presentation of knowledge and context, the representat5ion of knowledge and context and the ultimate framework including each independent organization, presentation and representation aim. The Organization of knowledge and context involved development of a common process which was derived from five major components: (1) General Problem Solver, (2) Sternberg paradigm, (3) concepts in Computer Science, (4) concepts in transdisciplinary research, and (5) the concept of organization as collection and storage of knowledge and related information content known as context, and then explored, via application of the process, to rich discipline specific abstracts. The Presentation of Knowledge and Context involved for this aim was to develop an independent approach to enhance the presentation of knowledge and related information content known as context constructed from four major concepts: (1) Ejigu et al. [21] separation of context data and context knowledge, (2) Dourish [13] concept, presenting knowledge and context as consistent, continual renegotiation, when matching action to state, (3) extending the presentation components, lines, spheroids, and edges, for representing relationships in graph theory [37], Entity Relationship Diagrams (ERD), Sequence Diagrams (SD), and State Transition Diagrams (STD) [38], and lastly, (4) an analogy to the concept of relating the motion of two particles as a frame of reference is measured differently by different observers [54]. The presentation of knowledge and context were then validated through application of the process to rich discipline specific abstracts. The Representation of Knowledge and context involved development of an independent approach to enhance representation of knowledge and related information content known as context derived from Newton's law of gravitation. The approach is explored via application to knowledge and context found within discipline specific abstracts rich in domain specific content. The Framework for Knowledge and Context is constructed by combining three independent components: (1) organization of knowledge and context, (2) approach for presenting knowledge and context, and (3) an approach for representing knowledge and context. The framework's application

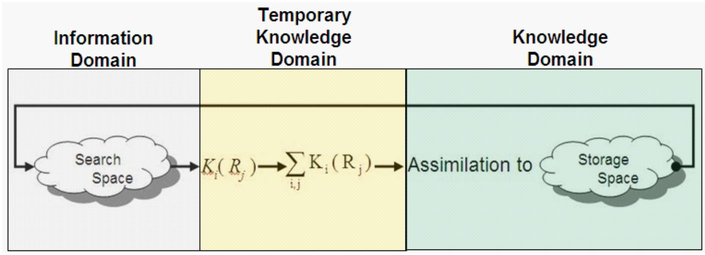

Figure 6.1 Recombinant kNowledge Assimilation Equation.

is subsequently explored via application to two independent discipline abstracts rich in domain specific knowledge and context.

6.4 Results and Discussions

6.4.1 Organization of Knowledge and Context

6.4.1.1 Introduction

This approach presented organization of knowledge and context and was constructed from three discrete components to collect and store knowledge and context per Ejigu et al. [21]. Collection and storage together are considered analogous to the term assimilation, in this section. First, a new knowledge and context assimilation equation known as knowledge assimilation equation was developed. Second, a new concept map diagram comprising natural discipline knowledge formation was developed. Third, a collection and storage diagram representing the knowledge assimilation equation was developed and applied to an abstract rich in domain specific knowledge and context.

6.4.1.2 Collection of Knowledge and Context

Llinas et al. [53], observed that the synthesis of combining two bits of information into knowledge fusion requires knowledge and pedigree/historical information, which was context. Rowley and Hartley[30] describe knowledge as learning accumulation, hence, to accumulate knowledge and context "collective intelligence" was used as described by Gruber [8]. Therefore, not only is effort required to observe, select, and physically take hold of information, but also necessary is the understanding that collected knowledge and context has a historical relationship to existing information. Gruber [8] states that collective intelligence emerge if data collected from all people is aggregated and "recombined" to create new knowledge. To form an understanding of the relationship between different knowledge and contexts when assimilating knowledge, the associated relationships can be written symbolically as knowledge Ki and the associated context relationship Rj where, Ki(Rj) represents a recombination of knowledge and context and finally represents the assimilation storage into the core domain repository. This is depicted in knowledge assimilation Figure 6.1. Figure 6.1 depicts a conceptual search space where a user would search for discipline specific knowledge and context within the Information Domain. The combined knowledge and context is then assimilated in the Temporary Knowledge Domain into a storage space shown on the right of the equation, the Knowledge Domain, to store knowledge and context which has reached a threshold level in the mind of the assimilator.

6.4.1.3 Storage of Knowledge and Context

Today, existing databases housing vast bits of information do not store the information content of the reasoning context used to determine their storage [21]. The knowledge collection and storage formula was therefore developed to include and store relationship context along with knowledge, recursively. This means that, each act of knowledge and context pairing shown as in equation shown in Figure 1 $\sum_{i,j} K_i(R_j)$, recursively examined all of the previous relationships as they were recombined into storage since they were all related and dependent on each other. Recursive refinement then occurred, per iteration of relationship pairing. Recursive refinement occurred when the user found what was looked for shown as $K_i(R_j)$, using interrogatives, (e.g. who, what when, where, why and how) [19-20]. The information content contributing to finding the answer then has significant value and therefore, a higher degree of permanence in the mind of the stakeholder [55]. Therefore, the information content has reached a threshold where retaining the knowledge and context has become important.

The assimilation to storage can take physical and virtual form. Virtual storage can be described as the caching of a collection of temporary knowledge in the mind of the user per Ausubel et al. [56] along with a set of historical pedigree of preconceived/tacit or explicit knowledge and context per Nonaka [2] used to solve an issue at hand. Physical representations of assimilated stores are well known (e.g. libraries, databases, coin or philatelic collections.) However, whether virtual or physical, each unit of storage has a series of reasons or pedigree as to why it was collected and stored, or in the case of knowledge and context assimilation, why a knowledge and context relationship was created. For this result it is assumed that while knowledge and context are contemplated in the mind of the user [56], that knowledge and context are stored virtually until the point in time the user reaches the threshold where it is believed the virtual knowledge is of enough quality to become stored in a physical repository for someone else to see or use, or that a virtual memory constraint has been reached and thus the memory needs to saved physically so that it might not be lost if not captured.

6.4.2 Presentation of Knowledge and Context

Figure 6.2 represents a KRT. This approach for presentation of knowledge and context and was constructed to present five discrete attributes, namely, time, state, relationship distance, relationship value, and event sequence. In this figure, the timeline represented by the blue arrow from left to right, shows the events or state transitions in sequence and captures the decision points. During each iteration of presentation of knowledge and context, intrinsic values were captured and placed close to each colored knowledge component. In Figure 2, these are represented as words under the cycles. The Basic Sentence Decomposition depicts how a KRT looks when it represents a sentence decomposed into pieces; in this case words. The red triangles, added next, depict a particular state for each iteration in the KRT development cycle. For emphasis, each colored sphere was built into the depiction and added in sequence to represent the fact that each word follows the other. Each icon represents each word of the sentence. The relative

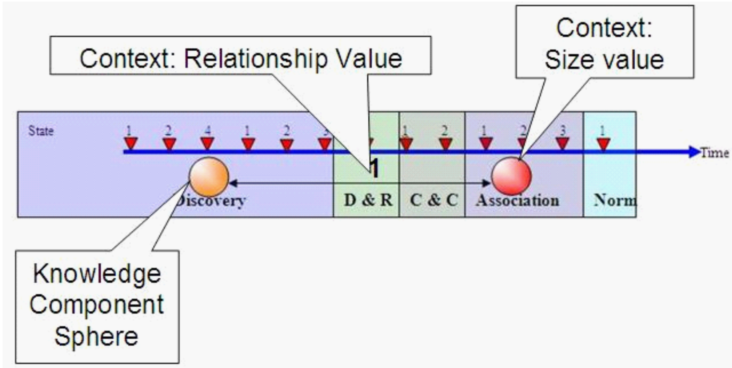

Figure 6.2 Knowledge Relativity Thread.

values in this Basic Sentence Decomposition between each sphere are perceived to be of the same value to each other. Therefore, the lines are the same distance as well. Since, this base representation depicted in Figure 2 can present time, state, and sequence, as well as, relationships, the challenge was addressed as described by Dourish [13] to create presentation of context which can visually capture and manage a continually renegotiation and redefinition of context as development of knowledge occurs over time.

Figure 3 shows a KRT presentation approach to comparing the knowledge and context between two distinct discipline abstracts. Specifically, for this example, Bioscience 1 abstract and Video Processing 1 abstract were compared to each other to find similarities, per the need as prescribed by Habermas [57] to have an original set of criteria to meet and by Ertas et al. [23] to find and integrate concepts and methods from other disciplines which share similar levels of analysis and finally by Trochim [34] which described the need to present knowledge and context so different groups can collaborate their different thoughts and ideas in a structured conceptualized manner. Therefore, a systematic approach was taken comparing and presenting the knowledge and context of each aggregated object to the other. As part of this enhanced systematic approach, each aggregated object in each abstract is compared to each of the other aggregated objects in the other abstract. As this comparison occurred, the user captured each event in a log for every action and related reason which transpired during the systematic comparison. The details of the log are explained later in this paper. This logged information was used to help subsequent users gain a more complete understanding of the knowledge and context and thereby interpret a previous KRT collaboration presentation blueprint. The KRT visualization of this comparison shown in Figure 6.3 depicts the sequence of the aggregated objects that were compared. An important distinction about the observation of each comparison is that each was made from the perspective of the aggregated object being compared. This is defined conceptually as an analogy to Hibeller [54] where the concept of relating the motion of two particles is as a frame of reference and is measured differently by different observers.

Figure 6.3, is a snapshot in time, using simple length measures to show relative distance of a relationship which is described later in paragraph 6.3.3 , for comparison of aggregated object 1 in the Bioscience 1 domain abstract or Bio1_AO1 compared to each aggregated object from Video Processing abstract 1 or Vid1_AO1 to Vid1_AO5. Itera-

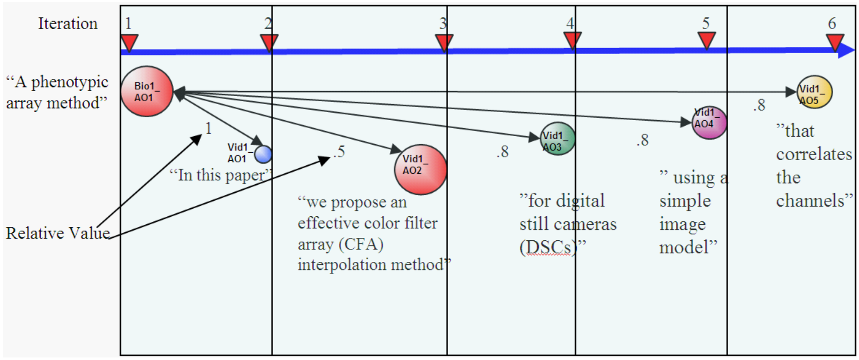

Figure 6.3 Comparing Abstracts using KRT.

tion 1 shows Bio1_AO1="A phenotypic array method" solo. Iteration 2 shows Bio1_AO1 being compared to Vid1_AO1="In this paper." The relationship is not similar and therefore has little value and is presented by the smaller spheroid and distant relationship set namely to L1. By contrast, iteration 3 shows an equal size red spheroid showing an overlapping match was found (e.g. the word "array"). Meaning Bio1_AO1 has the word "array" in the text as does Vid1_AO2, thus presenting a change in relationship shown as a different length L2 as compared to Bio_AO1 and Vid1_AO1 (1). The reason why the relationship between Bio1_AO1 and Vid1_AO2 is not closer than L2 is that though the relationship has been found to be textually similar, until additional information content is gathered and understood as per Brillouin's [9] assertion that information has no value until it has been thought about, a final assertion can not be made that these two aggregated objects are exactly the same. Iteration 4 shows Bio1_AO1 compared to Vid1_AO3="for digital still cameras (DSCs)." The green spheroid is larger than the blue spheroid Vid1_AO1 because, at initial look, substantive information such as "digital still camera" presents additional information which might be relative to Bio1_AO1="A phenotypic array" when additional comparisons and knowledge and context are obtained. The distance of the relationship is therefore currently a bit further than that of Vid1_AO2 (L2), but closer than Vid1_AO1 which has little to no similarity, at this point, to Bio1_AO1. Lastly, Vid1_AO4 and Vid1_AO5 have similar attributes as Vid1_AO3 and therefore their knowledge and context relationship settings are similarly set.

6.4.3 Representation of Knowledge and Context

The representation of knowledge and context formula is introduced here and is presented by Equation (2). The independent results which follow are mathematical evaluations extended from Newton's law of gravitation shown in Equation (1). Newton's Law of Gravitation formula is,

$$F = G\frac{(M_1 M_2)}{r^2} \quad (1)$$

where:

F is the magnitude of the gravitational force between the two objects with mass,

G is the universal gravitational constant,
M_1 is the mass of the first mass,
M_2 is the mass of the second mass, and
r is the distance between the two masses.

This equation was used as an analogy for the derivation of mathematical relationship between a basis made up of two objects of knowledge.

Abstracting Newton's Law of Gravitation

An analogy of Equation (1) that represents relationships between two objects of knowledge using context is written as Equation (2) shown below, which describes the components of the formula to represent relationships between two objects of knowledge using context:

$$A = B\frac{(I_1 I_2)}{c^2} \qquad (2)$$

where,
A is the magnitude of the attractive force between the two objects of knowledge,
B is a balance variable,
I_1 is the importance measure of the first object of knowledge,
I_2 is the importance measure of the second object of knowledge, and
c is the closeness between the two objects of knowledge

Comparing the parameters of Equation (1) and Equation (2) F and A have similar connotations except F represents a force between two physical objects of mass M_1 and M_2 and A represents a stakeholder magnitude of attractive force based upon stakeholder determined importance measure factors called I_1, and I_2. As an analogy to F in Equation (1), A's strength or weakness of attraction force was also determined by the magnitude of the value. Hence, the greater the magnitude value, the greater the force of attraction and vice versa. The weighted factors represented the importance of the objects to the relationships being formed. The Universal Gravitational Constant G is used to balance gravitational equations based upon the physical units of measurement (e.g. SI units, Planck units). B represents an analogy to G's concept of a balance variable and is referred to as a constant of proportionality. For simplicity, no units of measure were used within Equation (2) and the values for all variables only showed magnitude and don't represent physical properties (e.g. mass, weight) as does G. Therefore, an assumption made here is to set B to the value of 1.

For simplicity, all of these examples assume the same units and B was assumed to be one. The parameter c in Equation (2) is taken to be analogous to r in Equation (1). Stakeholder perceived context known as closeness c represented how closely two knowledge objects (KO) are related. Lines with arrows are used to present the closeness of the relationships between two pieces of knowledge presented as spheroids.

The representation of knowledge and context approach depicted in Figure 6.4 is a representative structure of knowledge and context as a snapshot in time for Bioscience 1 abstract. The first word of Bioscience 1 abstract is the word "A." "A" by itself has little

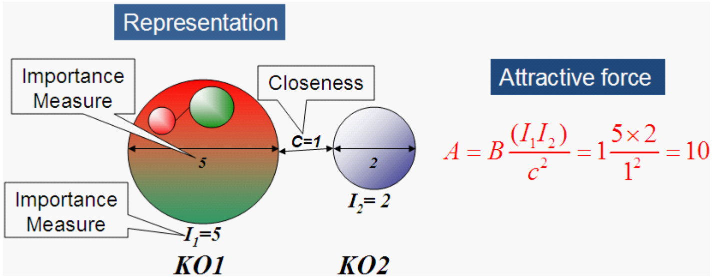

Figure 6.4 Representation of Knowledge Object and Context.

meaning. However, it was still considered part of this abstract and was therefore marked as object of knowledge 1 (KO1) within the abstract. As the abstract was read and more information content was gained and understood, "A"'s knowledge value changed. Currently, all that is known at this juncture is that "A" described a singular entity and has foreshadowed that something will follow. Hence, that has some small value and creates cognitive structure in the mind of the "learner" per Ausubel et al. [56]. It is depicted in Figure 6.4 as knowledge object 1 (KO1) (e.g. red spheroid with the number 1) and mentally place only a small value on it for now because of our lack of knowledge. Next, as reading the abstract continued, the second word is found and marked as knowledge object 2 (KO2), "phenotypic." Figure 4, representing the knowledge and context of the mind of the learner now depicts KO1 and KO2, as related to each other. The word "A," or KO1 has a smaller spheroid than KO2, and therefore, structurally represents a smaller context of importance measure shown as a diameter, $I_1 < I_2$. The line distance between KO1 and KO2 structurally represents "closeness" or how closely related the objects are perceived to be to each other. The word "A," KO1 has small relationship to KO 2. Hence, KO1's relationship to KO2 was characterized simply as residing within the same abstract and one of order sequence. Therefore, the knowledge objects remain further apart, shown as closeness or "c." Therefore, the snapshot in time shows a structural representation of knowledge relationship between two knowledge objects along with the context of magnitude importance value shown as the arrows representing the diameter magnitude of each knowledge object.

Using Equation (2), the value of the attraction force $A_{1\to 2} = 5\times 2$ divided by the relative closeness/perceived distance^2 = 1. Hence, the attraction force A in either direction was 10. The value of 10 is context which can be interpreted in relation to the scale. The largest possible value for attraction force A with the assumed important measure 1-10 scale is 100, therefore a force of attraction value of 10 was relatively small compared to the maximum. This means that the next stakeholder/ researcher understood that a previous stakeholder's conveyance was of small relative overall importance. However, the closeness value of 1 showed that the two objects were very closely related. Figure 4 therefore shows that when using Equation (2), if relationship closeness and/or perceived importance measure of the knowledge objects change value, as new knowledge or context is added and evaluated, then it follows that relationship force of attraction will change.

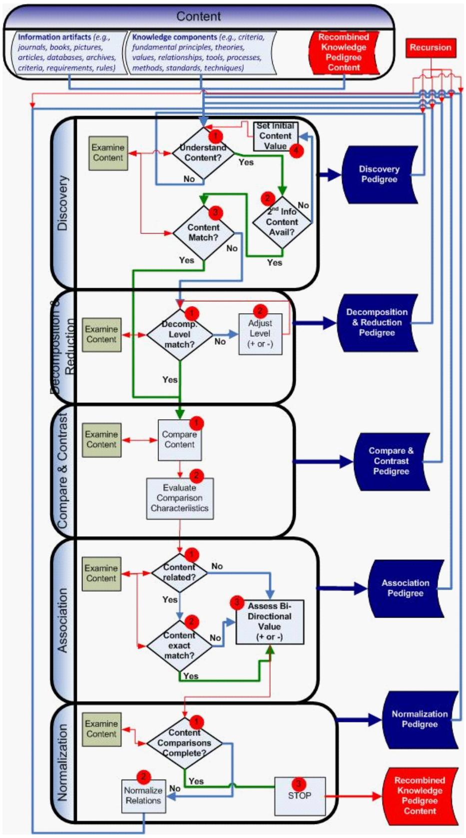

Figure 6.5 RNA Flow Diagram.

6.4.4 Framework to Enhance Knowledge and Context

The framework developed in this research to enhance knowledge and context is shown in Figure 6.5 and was referred to as the Recombinant kNowledge Assimilation (RNA). RNA and is made up of a combination of the organization of knowledge and context, the presentation of knowledge and context, and the representation of knowledge and context [21]. The three components make up the core pieces essential for building a knowledge and context framework [21, 47]. Cross discipline domain research [28-29, 31, 33, 58] shows clearly that although all researchers use their own flavor of unique rules, methodologies, processes and frameworks, they use a core set of components for gathering, analyzing, organizing and disseminating their work. Recently Liao et al. [47] and Ejigu et al. [21] defined these processes as: collection, storage, presentation and representation.

6.4.4.1 RNA Flow Diagram

The RNA Flow Diagram shown in Figure 6.5 is shown to describe the flow of the processes within the framework [21]. It is similar to the Liao et al. [47] framework that collects, stores, presents and represents knowledge and context. The RNA flow diagram comprised three major, discrete parts. First, "Content," which represents all information content input into the flow diagram. Second, "Sub-Processes" for synthesizing knowledge and context. Third, storage repositories known as pedigree bins, where knowledge and context was stored during compilation. Compilation is a path beginning from basic information content in the Information Domain, to the Knowledge Domain, as described by Brillouin [9], where a set of initially "useless" information is "thought about" and turned into knowledge. This knowledge becomes the collected pedigree knowledge and context, just as Gupta and Govindarajan [48] collected knowledge flow for measurement, for the next researcher, as shown by the blue arrow leaving the Knowledge domain and feeding back into the Information Domain in Figure 6.6. In the RNA flow Diagram shown in Figure 6.5, each diamond shaped box represents a decision point. This is a critical point where a stakeholder of the process contemplates the decision to be made using any previous knowledge components acquired prior to making the decision as defined by Kim et al. [6]. Each red spheroid represents a sub-step within each of the larger components of the RNA process. These red spheroids are used to identify an important portion of the process. Red arrows signify action and green arrows represent "Yes" answers to a decision, hence the red lines represent a stakeholder of the process performing an action such as, collecting more information content known as used knowledge during process execution [6] for the eventual goal of establishing a more complete understanding of knowledge and context during processing at a decision point. All other blue arrows, represent either "No" answers or neutral transitions to a subsequent step in the process to track the flow of the process and thus continually collect information content used to make the "No" decision.

The RNA process flow begins when a reason or need was established to ask a question and to want to search for an answer. This causes the establishment of a set of criteria or rules which govern what was to be discovered [57]. These criteria govern the activity performing the bottom-up processing and recursively evolving the building of knowledge and context. Once the criteria has been established and understood passing from the Information Domain thru the Temporary Knowledge Domain and finally captured in the Knowledge Domain, the RNA sub-processes begin processing based upon the defined rules.

RNA processes criteria just as other information content. Each is collected from the Information Domain, "thought about" [9] in the temporary Knowledge Domain and subsequently placed into the Knowledge Domain for use as shown in Figure 6.6.

The upper rounded box labeled "Content" represents all information content which can potentially be used when performing the steps of the RNA process to build knowledge components. This is the set of initially "useless" information built into knowledge, as described by Brillouin [9], and is represented by the information content under the Information Domain search space in Figure 6.6. Hence, when a stakeholder begins the process of examining information, it is the information content which was initially observed, using the senses, and then subsequently "thought about" and understood, via collecting, representing, presenting, and storing, until the stakeholder satisfies the desired threshold of understanding defined by the initiating criteria. The criteria were considered information content as well, since a set of criteria was established to setup rules to compare against until satisfied. The gathering and comparisons, shown by the red arrows in Figure 6.5, occur to the point where a stakeholder believes an understanding has been reached during each step in the process, just as Brillouin [9] defines knowledge as resulting from a certain amount of thinking. Therefore, the developed sub-Processes: Discovery, Decomposition and Reduction, Compare & Contrast, Association, and Normalization process information content based upon a set of initial criteria.

6.4.4.2 RNA Synthesis Sub-processes

The RNA common process contains five functional sub-processes, labeled Discovery, Decomposition and Reduction, Compare & Contrast, Association, and Normalization. These sub-processes synthesize knowledge and context within the framework down the left side of Figure 5. These sub-processes operate in the process domain [59] as shown in Figure 6. Discovery encompasses the review and understanding of existing knowledge and /or in the case of disciplines, the review of a discipline's fundamentals and/or First Principles. Decomposition & Reduction decomposes the domain knowledge into "bite size" digestible bits of information and reduces the representative domain knowledge to a core capability. Compare & Contrast, a cognitive examination process assimilating facts and information, comparing each to the other, looking for evolving associations, Association for establishing and assigning relationships between any two objects of information, and Normalization for functionally combining commonalities into a normalized form and validating the result. Finally, recursion is depicted as the blue domain knowledge feedback loops, which represents the iterative recursive refinement taking the knowledge gathered during each iteration and using it as input into the next iteration of the RNA process.

Since RNA's synthesis tasks, depicted in Figure 5, extend concepts from mature disciplines including Software Engineering. Specifically, recursion is shown by the feedback loops from each of the processes [31] [32]. Recursion is well suited for the goal of creating objects of information using a bottom-up approach, iteratively building its components and attributes through a series of decisions. Hence, RNA implements the mature bottom-up approach for developing knowledge and context as discipline components, derived from discipline domain abstract readings and the recursive nature of the process shown by the feedback loop in Figure 5 which recombines knowledge and context.

6.4.4.3 Discovery

In the Discovery sub-process, the stakeholder must gather at least one additional piece of information content to make a comparison. During the comparison process, the stakeholder was asking questions and developing answers, just as in the Sternberg Paradigm [29]. However, the difference was that RNA developed and retained empirical information during each specific step. Each question and answer was developed and captured at each step. All thoughts regarding reasoning and the information content used to develop the comparison were also captured at each step. Consequently, the value the stakeholder placed upon each piece of information content, shown in Discovery step 4, can be temporarily saved mentally or stored physically to retain the context of the thoughts being developed. This was designated by all the dark blue arrows and boxes labeled (e.g. Discovery Pedigree). After the first piece of Information Content has been observed, the flow diagram shows that a stakeholder must have at least one other piece of information content in order to form a comparison. Hence, the RNA process flow expands using a red arrow to depict the setting of an initial value property for the first piece of content and then continues back to Discovery step 1 to observe a 2nd piece of information content in order to form a comparison.

Finally, if the stakeholder has found two pieces of content that was believed to be an exact match and was exactly what has been searched for, then the flow diagram resumes in the Association building block where a determination was made as to the bi-directional value of force attraction of matching relationship pairs. If there was not an exact match then the next Decomposition and Reduction building block in the flow diagram was used to assist in determining whether there was simply an inequality in the comparison, and the Decomposition and Reduction flow block assists in rectifying that issue.

6.4.4.4 Decomposition & Reduction

The next step in the RNA Process was Decomposition and Reduction. This phase extends and expands GPS [27, 60], used to solve problems by successively reducing the difference between a present condition and an end goal. This was important because this section of the flow diagram was built so the stakeholder can establish a comparison level by which one can create comparisons more easily. Therefore, decomposition expands the RNA flow diagram as shown in box 2, and constitutes the act of slicing the contextual bonds of a relationship between two pieces of information and comparing the logical context level to assess whether information content should be further sliced or whether information content should be aggregated instead. The process of decomposition and reduction to practice based upon knowledge and context is similar to the concept of graduated/granulated in fuzzy logic [4]. As expressed in the Decomposition definition above, a document can be sliced into paragraphs and paragraphs can be sliced into sentences.

However, this Decomposition and Reduction decision spot in the flow diagram is built so words can also be aggregated together into sentences, or so characters can be aggregated into words. Thus, the red arrow from the box labeled “Adjust Layer Up or Down” was created showing that the stakeholder decides whether the content being compared was at the same logical context level/OEA. As before, the capture of the reasoning and meanings behind the decisions to aggregate or decompose was gathered and the dark blue pedigree repository box was created to depict the pedigree storage. The flow diagram then was built to feed back, all pedigrees from all phases, into the information content repository each time new context, knowledge or information content is generated as output from the flow diagram.

The reasoning captured during decomposition can give valuable insight into the stakeholder context. For example, it is well known that words can have multiple definitions, and when they are aggregated together into sentence form they can portray different emphasis and meanings just by their sequence. Therefore, capturing this as pedigree provides the next evaluator of this information valuable reasoning context which could otherwise easily be misinterpreted. The detail log shown in Appendix A, was created when abstracts were processed. The log describes details of state, sequence, and events which give insight into how the process was used to generate knowledge components from information content. Specifically, the Bioscience paper will be processed, and labeled pedigree will be shown, using the RNA flow chart below. The specific examples will show that the capture of the relationship pedigree along with the stakeholder weighting of relative relationships provides valuable insight into (e.g., who, what, when, where, how and why) relationships were developed and how the process contributes to the benefit of subsequent researchers evaluating the conveyed thoughts. Once the objects can be equated at the same contextual level, the OEA's can be passed to the next stage, Compare & Contrast.

6.4.4.5 Compare and Contrast

The Compare & Contrast building block was then added to capture the specific characteristics of the OEA relationship through a series of interrogatories. At this stage, simple interrogatories such as, Who, What, When, Where, How, and Why as well as more detailed questions can be asked based upon the context to determine relationship specifics. Hence, the box for comparing content was added to the flow diagram and then the "Evaluate Characteristics" box was added to designate the need to perform an analysis of the characteristics captured such that the next building block can be added called Association.

6.4.4.6 Association

The building block Association is where the critical analysis was performed for determining the value of the relationships formed during RNA. The decision box is added to designate the need to determine if, based upon the analysis captured during Compare and Contrast, the objects are related to one another. The flow diagram box is then added to designate the need to assess the value strength or weakness of the relationship bi-directionally. A value assessment of each object to the other is performed, based upon the context of the analysis. As in all the previous sub-processes, the iterative decisions and reasoning is captured in the created blue pedigree boxes for ultimate feed-back into the content repository box.

6.4.4.7 Normalization

The next building block added to the RNA flow diagram is the Normalization box representing evaluation of the overall content of the relationships developed under a set of rules governing what to discover. This is analogous to an automobile which is made up of many parts. Each part has an independent function. Each set of parts is related to each other based upon some specific context (e.g. Rim and Tire). However, the sum of all valued parts equals a car, but each part has a perceived value to the overall value of the car as well. An engine might be perceived as having more importance than the radio. Therefore, the Normalization building block was added to designate the need to evaluate all relationships created under the guise of a given criteria context to each other bi-directionally. If all comparisons are complete, then the RNA process flow diagram process stops and the Normalization pedigree is added to the content repository through the blue feedback pedigree box. The pedigree reasoning which was derived from normalizations of the all the relationships created under a certain criteria are related to each other to achieve a cohesive overall value chain of the relationships to each other and their importance to the overall context of the criteria.

In summary, the new RNA Common Process depiction in Figure 5, describes a process which can be generalized for use in a domain where knowledge assimilation is

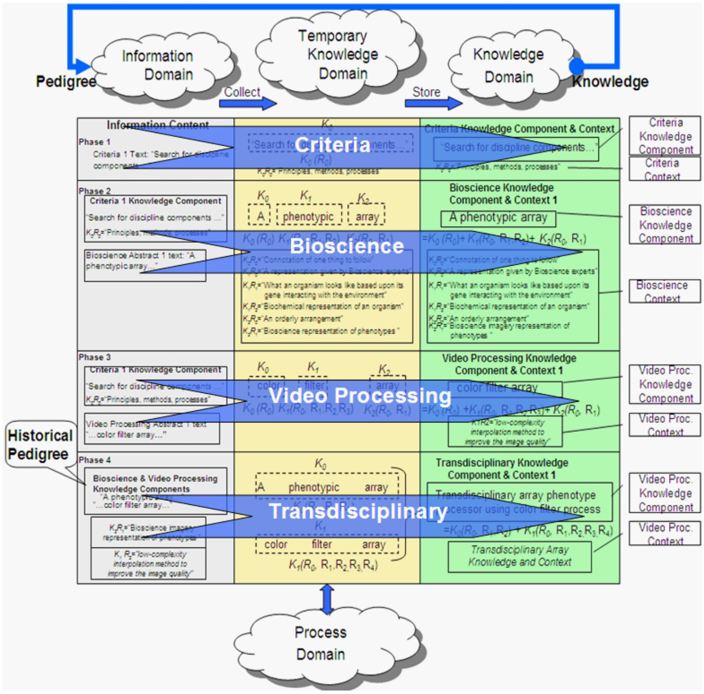

Figure 6.6 Knowledge and Context Processing.

desired, by extending a bottom-up approach in OOD and applying concepts the natural language interrogatives found in 6WH. Therefore, RNA follows a path of creating knowledge and context in a natural manner combined with techniques described herein, for collecting, representing, presenting and storing.

6.4.4.8 Application of RNA to Journal Abstracts

The RNA common process was applied to research journal abstracts in Bioscience [61] and Video Processing [62]. The elements of the constructed RNA framework and subprocesses were applied to each journal abstract, yielding criteria knowledge component and context, knowledge component and context, and transdisciplinary knowledge component and context. This is depicted in by the four phases in Figure 6.6.

Additionally, the snapshot in time shown in Figure 6 depicts how the framework combined the use of RNA as a common process, the presentation approach for knowledge and context, and the representation approach for knowledge and context. Together the framework constructed and refined a sustainable blueprint of knowledge and context from abstract excerpts in Bioscience and Video Processing. Thus, via the log files and pedigree bin storage mechanisms, it was shown how a cohesive user collaborative [50] dependency trail of knowledge and context was created. The collaborative nature of the process showed how "collective intelligence" was created as defined by Gruber [8]. Therefore, the outcome satisfied the objective of locating reliable and relevant information out of an environment of rich domain specific Bioscience and Video processing abstracts. Finally, upon comparison of the two abstracts using the framework comprised of organization, presentation, and representation, of knowledge and context, the outcome showed creation of transdisciplinary knowledge component and context.

6.5 Conclusion

A framework was constructed from the organization, presentation, and the representation of knowledge and context. The organization was derived from the concept of collection and storage, general problem solver, derived from Newell et al. [27] and Simon [28] who together developed models of human mental processes. Sternberg paradigm [29], and tenets of transdisciplinary engineering as defined by Tanik and Ertas [5]. The presentation was constructed from five discrete attributes, namely, time, state, relationship distance, relationship value, and event sequence from computer engineering and mathematics. The representation was derived by using Newton's law of gravitation as an analogy. Finally, the framework was applied to abstracts from research manuscripts and extracted disciplinary and transdisciplinary knowledge and components and therefore was able to as described by Ertas et al. [23], discover important knowledge within one discipline can be systematically discovered, and recombined into another, and via combined engineering visualization mechanisms and collaborative KRT blueprints satisfied Stokols [51], need to achieve a more complete understanding of prior research collaborations and sustain future ones. Finally, the framework satisfied the need as described by Liao et al. [47], enabling transition from data, information and knowledge to new knowledge.

Therefore, using RNA, disciplinary and transdisciplinary knowledge components and context were systematically discovered from tacit and explicit knowledge and context, allowing future generations a mechanism to dynamically interact with ever changing research knowledge, assimilating it to form explicit new knowledge while retaining the causal pedigree. Thus, RNA was able to enhance transdisciplinary research knowledge and context.

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7 Designing Transdisciplinary Discovery and Innovation: Models and Tools for Dynamic Knowledge Integration

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Abstract

This chapter presents challenges faced in rapidly accelerating technological development and the need for a transdisciplinary approach to engineering systems. An analogy is drawn with theories of technical system development to propose a mechanism for dynamic knowledge integration using transdisciplinary approaches. The mechanism for dynamic knowledge integration is based on a three-level progression of the scope of transdisciplinary research activities. Concepts and tools from engineering design and innovation are used to explain challenges and opportunities for the future of transdisciplinary research, and preliminary measures for transdisciplinary and interdisciplinary knowledge integration are discussed. Validation of transdisciplinary research is then discussed in light of approaches to philosophy of science and the sociology of intellectual discourse. Examples are given of transdisciplinary research areas that combine engineering design with other fields such as sustainability, biology, and management of technology.

7.1 Introduction

In this paper, the author argues for the need of a transdisciplinary research and educational framework to address large-scale, modern engineering systems and to prepare engineers, designers, and researchers of the future. In discussing this need, the author considers several issues: the theoretical issues involved in crossing disciplinary boundaries, the development of more comprehensive understandings of large-scale problems, and the integration of concepts and methods from multiple disciplines.

During the last decade, the number of complex problems facing society has exploded, and the technical knowledge and understanding in science and engineering required to address these problems is rapidly evolving. The National Academy of Engineering (NAE) has presented a list of the twenty greatest engineering achievements of the Twentieth Century. These engineering contributions celebrate technical achievement and highlight the impact of engineering on the quality of life [1]. All of them have created complex engineering systems and result from the contributions of multiple disciplines. A few examples of the rapid pace of technological changes are the groundbreaking advancements in semiconductor and software technologies, the biosciences, nanotechnology, and cognitive sciences [2].

In addition to the great achievements of engineering, the list of failures is growing as well. Recent failures include delayed schedules and cost overruns, projects that go back to the drawing board halfway through the development process, and those that never get implemented at all [3-5]. Often these failures arise at the interface between the engineering systems and their social-technical interfaces. Many trends pose challenges—or opportunities—for the future: globalization; energy demands; environmental impacts; social, cultural, political, and economic forces; new human-machine interactions; new, open ways of distributing knowledge; and a more pervasive presence of technology throughout society [6-8].

The world has changed due to globalization, including multinational R&D facilities in developing countries, high-tech production in China, and the outsourcing of service jobs to India. Yet, engineering education—especially at the undergraduate level in the US—has remained substantially unchanged since the 1950s when the current structure of engineering education was established to meet cold-war concerns about science as codified in the Grinter report of 1955 [9-11].

As Nobel Laureate Herbert Simon stated, "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..." [12]. The last two decades of designing large-scale engineering systems has taught us that neither mono-, multi-, nor inter-disciplinary approaches provide the environment that is necessary to promote the level of synthesis and collaboration that is necessary to extend beyond existing disciplinary boundaries and produce truly creative and innovative solutions to large-scale, complex problems.

This paper aims to clarify some of theoretical issues involved in crossing disciplinary boundaries from an engineering perspective, contribute to a more holistic understanding of large-scale problems, and describe from a technological standpoint, the integration of concepts and methods from multiple disciplines. This chapter is structured as follows:

Section 7.1 introduces the challenges faced because of rapidly accelerating technological development and motivates the need for a transdisciplinary approach to engineering systems. Section 7.2 defines transdisciplinary research, shows the importance of engineering and design, and discusses open and mass innovation concepts. Section 7.3

draws on an analogy with theories of technical system development to propose a mechanism for dynamic knowledge integration using transdisciplinary approaches.

The mechanism for dynamic knowledge integration is based on a three-level progression of the scope of transdisciplinary research activities. The author draws parallels between transdisciplinary research efforts and analogous activities in engineering innovation. Concepts and tools from engineering innovation are used to explain challenges and opportunities for the future of transdisciplinary research, and preliminary measures for transdisciplinary and interdisciplinary knowledge integration are discussed. Validation of transdisciplinary research is then discussed in light of approaches to philosophy of science and the sociology of intellectual discourse.

Section 7.4 describes examples of transdisciplinary research that combine engineering design with other fields such as sustainability, biology, and management of technology (management and economics). Section 7.5 discusses challenges in creating a transdisciplinary science for engineering. Section 7.6 presents a summary and conclusions.

7.2 Need for Transdisciplinary Approaches

Although there may be much buzz these days about interdisciplinary and multidisciplinary research, efforts at cooperation between disciplines are often ad hoc, driven by the desire to secure funding for a particular project [13]. Is there an underlying connection between the disciplines, and if so, what is it?

7.2.1 Characteristics of Transdisciplinary Approaches

Kollman and Ertas provide a summary of definitions of transdisciplinary approaches and distinguish transdisciplinary efforts from other cross-disciplinary approaches such as multidisciplinary and interdisciplinary efforts. They present the results of a survey that show that transdisciplinary efforts are characterized by sustained collaboration and a high quality of integration among methods and approaches [14] .

Efforts to define and establish transdisciplinary research can be traced back to the early 1970s [15, 16]. According to the Oxford English Dictionary, the term transdisciplinary appeared in 1972 and may be defined as “Of or pertaining to more than one discipline or branch of learning.” From its earliest usage, transdisciplinary indicates greater cooperation and integration between disciplines than do interdisciplinary or multidisciplinary [17]:

> 1972 E. JANTSCH in *OECD: Interdisciplinarity* II. i. 105 The ultimate degree of co-ordination in the education/innovation system,...which may be called *transdisciplinarity,* would...depend on a common anxiomatics [sic]....The whole education..system would be coordinated as a *multi-level, multi-goal* system, embracing a multitude of...interdisciplinary two-level systems, which... will be modified in the transdisciplinary framework.

Transdisciplinary education and research take collaboration across discipline boundaries a step further than do multidisciplinary and interdisciplinary programs. Transdisciplinary goes beyond multidisciplinary and interdisciplinary to mutually share methods and subjects between disciplines [18]. Nicolescu describes the three-fold nature of transdisciplinarity: “Transdisciplinarity concerns that which is at once between the disciplines, across the different disciplines, and beyond all disciplines.” He continues by stating that its "goal is the understanding of the present world, of which one of the imperatives is the unity of knowledge" [15].

Multidisciplinary research is characterized by studying a research topic from the perspective of multiple disciplines at the same time. Specifically, a multidisciplinary approach uses methods from two or more disciplines to examine a common topic. According to Kollman and Ertas, "Multidisciplinary teams do cross discipline boundaries; however, they remain limited to the framework of disciplinary research" [14]. In general, researchers from different disciplines work independently, each from his or her own discipline-specific perspective to address a common topic.

Interdisciplinary research involves the application of a method from one discipline to topics studied by other disciplines. According to Kollman and Ertas, "In...interdisciplinary activities, researchers from different disciplines work jointly on common problems by exchanging methods, tools, and concepts...to find integrated solutions" [14]. In other words, interdisciplinary research concerns the transfer of techniques–methods–between disciplines.

Most recently, Ertas lists several characteristics of transdisciplinary research. Namely, it "us[es]...shared concepts, frameworks, tools, methodologies and technologies to solve common unstructured research problems; eliminates disciplinary boundaries for strong collaboration; redefines the boundaries of natural science, social science, humanities and engineering by bridging them, and leads [to] the development of new knowledge, shared common conceptual frameworks, tools, methodologies and technologies" [19]. Engineering must play a vital role in advancing transdisciplinary efforts, and conversely transdisciplinary efforts will further advance engineering, technology, and science.

7.2.2 Importance of Engineering and Design

Having a fundamental understanding of engineering systems has become increasingly important as the pace of technological development has accelerated due to global collaboration and competition. Technology has driven changes in design and development processes for engineering systems [20]. Products have become integrated engineering systems, and design and production requirements cross disciplinary boundaries. Knowledge from many disciplines—within engineering as well as other disciplines outside of science and engineering, such as business, social sciences, medicine, etc.—needs to be integrated to create effective systems or products.

According to Ertas, the essence of the transdisciplinary approach is "a foundation of design fundamentals and process development and management....This core is then surrounded by knowledge and skill 'tools' selected from various disciplines. These tools can be updated as needed to keep pace with developing technology" [20]. The process envisioned for achieving transdisciplinary engineering starts with "extract[ing] the common elements, design and process, from existing disciplines and synthesiz[ing] them into the foundation of the new transdiscipline...The transdisciplinary approach provides an umbrella of the core design, process, systems, and metrics common to all disciplines that [are] necessary for problem solving" [21].

Science alone will not be able to solve today's problems. Petroski has noted the importance of engineering and its neglect by society in comparison with science. In particular, Petroski believes that the creativity and initiative that mark engineering efforts are vital to addressing national and global challenges [22].

Public perception of engineering recognizes its importance to national and international competitiveness, economy, quality of life, security, but uncertainty about engineering among the general public remains. Conflicting perspectives on the essential attributes that comprise the engineering design process result in a lack of coherent criteria for introducing engineering to P-12 students and an inability to make engineering an attractive discipline for prospective students and to improve public perceptions of the contributions of engineering [23].

A recent study by the NAE highlights the challenges: The strongest association with the engineering profession that was identified by the general public and prospective students is the need for strong science and math skills among engineering practitioners. The authors of the report conclude that the commonly used approach of engineering outreach, namely emphasizing science and math and the practical benefits of being an engineer "may damage rather than increase the appeal of engineering." It overemphasizes their importance instead of placing these subjects "correctly, as just two of a number of skills and dispositions...necessary to [be] a successful engineer." The report instead recommends emphasizing "the inspirational, optimistic aspects of engineering" similar to the image of a "physician...who cures diseases and relieves human suffering." As they note, "The medical profession does not market itself to young people by pointing out that they will have to study organic chemistry or by emphasizing the long, hard road to becoming a physician" [24].

The difference between science and engineering can be captured in the statement by von Karman: "Scientists study the world as it is, engineers create the world that never has been." Sohlenius expands on this thought by explaining that an engineer "analyses what is, imagines what should be, creates what has never been, analyses the results of the creation," [25]. Simon contrasts the subjects of inquiry in science and engineering as "natural things: how they are and how they work" in contrast to "artificial things: how to make artifacts that have desired properties and how to design" [26].

To explain the overemphasis on science in engineering education requires a historical analysis of the forces that shaped engineering curricula after World War II. [27] According to Simon, "Schools of engineering...are all centrally concerned with the process of design....[yet] it is ironic that in [the twentieth] century the natural sciences almost drove the sciences of the artificial from professional school curricula, a development that peaked about two or three decades after the Second World War. Engineering schools gradually became schools of physics and mathematics....The use of adjectives like 'applied' concealed, but did not change, the fact" [26]. In particular, there was a shift towards "engineering science" subjects at the expense of design and manufacturing, even to the point that "the education system has treated engineering as synonymous with engineering science" [28]. "The idea that engineering is an 'applied science' had affected many programs adversely....[I]t sent the wrong message to engineering schools and reinforced the idea that the reductionism model of engineering research is what engineering research was all about. It downgraded technology innovation, design, manufacturing, and other related fields" [29].

While the shift to "engineering science" may have made sense in the context of the cold war [27], a re-emphasis on the creative aspects of engineering design is needed to maintain competitiveness in the current globalizing context.

7.2.3 Open and Mass Innovation Approaches

Innovation is a broader activity than invention—including not only the physical realization of a novel idea, but also including its acceptance. "The leaning towards cross-disciplinarity that characterizes much scholarly work in this area reflects the fact that no single discipline deals with all aspects of innovation. Hence, to get a comprehensive view, it is necessary to combine insights from several disciplines" [30]. The *Oxford Handbook of Innovation* provides a summary of the contribution of various fields to understanding innovation processes—yet does not include engineering. It lists economics, cognitive science, sociology, organizational science, management, economic geography, economic history, and history of technology [30].

An example of an innovation model from the discipline of management is the concept of *open innovation* [31, 32]. This view is based on the premise that useful knowledge is widely distributed, not only found within a firm. All companies need to seek out, connect with, and leverage these intra-firm and external sources of innovation. Moreover, the resulting products and systems can go to market from within or outside the firm as well. Open innovation research can be categorized according to its focus on the individual, organization, value network, or industry sector. It studies inflow and outflow of ideas and products and accompanying policies and enabling practices. According to Chesbrough et al., "The open innovation paradigm treats R&D as an open system. Open innovation suggests that valuable ideas can come from within or outside the company and can go to market from within or outside the company as well....Open innovation assumes that useful knowledge is widely distributed, and that even the most capable R&D organizations must identify, connect to, and leverage external knowledge sources as a core process in innovation" [31].

Globalization and cyberinfrastructure provide new mechanisms to create opportunities for *mass innovation,* which the author defines as "expanding and diffusing innovation activities to the general population through *connecting individual inventors and entrepreneurs* with the engineering tools and services needed to *assess and realize their novel design concepts*" [33].

In contrast to the firm-level approach of management science, an approach for evaluating innovation that is based on the technical content of a patented idea is the concept of *level of invention.* This was defined by Altshuller as a part of the theory of inventive problem solving (TRIZ) [34]. The five levels of invention are based on the resolution of system conflicts (caused by functional coupling) through transdisciplinary approaches. These levels of invention are based on the combination of the resolution of system conflicts and the borrowing of solutions from within or outside the discipline of the conflict [35-37]. Table 7.1 shows criteria for the five levels of inventions and their definitions.

It is notable that the definitions of these levels of invention take into account knowledge transfer and integration. Note that the higher levels of invention that are the goal of engineering design research and industrial practice *include by definition a greater degree of knowledge transfer from one discipline to another;* that is, knowledge for the higher levels of invention come from disciplines that are more intellectually distant from the problem being solved.

Table 7.1 TRIZ Level of Invention [35-37].

Level	Description	% of Patents [36]
Level 1	Apparent solution: A component intended for a task is used. No system conflicts are resolved.	32%
Level 2	Small improvement: An existing system is slightly modified. System conflict(s) are resolved through transfer of a solution from a similar technical system.	45%
Level 3	Invention inside paradigm: At least one system component is radically changed or eliminated to resolve system conflict(s); the problem and solution are within one discipline.	19%
Level 4	Invention outside paradigm: A new system is developed that resolves system conflict(s) using a solution that is interdisciplinary.	<4%
Level 5	Discovery: A pioneering invention is created, often based on recently discovered phenomenon.	<0.3%

7.3 Model of Transdisciplinary Knowledge Integration

In this section a model of transdisciplinary research is presented. The purpose of this model is to sketch a research process that can be applied in transdisciplinary research. The input of the process is a research question, and the output is a set of concepts, theories, and methods that can be tested or used for explanation and prediction. The main phases of the research process are data gathering, theory development, and theory validation. Each phase comprises one or more activities that are performed to generate, transfer, or assess knowledge. In some research projects, a research team works through all phases. In other projects, one research team initiates the work, and the results of this phase are passed to others who continue the research by working in subsequent phases [38, 39].

7.3.1 Parallels between Transdisciplinary Research and Engineering Innovation Activities

Research into engineering design has yielded insights into the nature and structure of the design process and formal, discipline-independent representations of design objects or artifacts—the product of the design process [40-42]. Additionally design research has produced many tools to aid design activities from either a discipline-independent or an intra-disciplinary perspective. While lacking a common terminology, many of the design theories have highlighted similar insights [43]: structures for modeling, processes, "design thinking," and tools. Each of these areas sheds some insight into creativity, innovation, and knowledge transfer.

Table 7.2 lists parallels between transdisciplinary research and engineering design, development, and innovation activities. The purpose of discussing concepts from engineering design and drawing an analogy between transdisciplinary research and engineering designs are two-fold: first, to clarify the role of transdisciplinarity in engineering design, and second, to explain the role of engineering tools and models in understanding and aiding transdisciplinarity.

As can be seen from the table of activities, there is a great deal of commonality between transdisciplinary research and engineering innovation processes. It is the belief of the author that models, theories, and methods from engineering design will be helpful in promoting and facilitating transdisciplinary research. Likewise transdisciplinary

Table 7.2 Activities in Transdisciplinary Research Compared with Innovation Processes.

Transdisciplinary Research	Engineering Innovation
Identification of need	Identification of need
Assessment of need, value and definition of scope	Assessment of innovative potential, financial analysis, and definition of project scope
Team formation and collaboration	Project control and collaboration OR Open innovation
Understanding models, methods, and theories	Functional modeling
Search for models, methods, and theories	Search for technologies
Selecting models, methods, and theories	Selection of technologies
Integration and creation of a research program	Integration and Implementation
Testing and validation	Testing and validation

research can broaden the perspective of engineers and promote the creation of more creative solutions than would be generated by traditional methods within individual engineering disciplines.

7.3.1.1 Models of Engineering Design Processes

Ross defines a model as "M is a model of A if M can be used to answer questions about A" [44]. This paper presents ideas for a model of transdisciplinary research activities for the use of either those interested in implementing transdisciplinary research processes or for those interested in explaining the events and outcomes of these processes. Common models of engineering design processes represent design activities in terms of functional modeling—identifying functional requirements and constraints that need to be satisfied for a given set of customer needs, mapping between various design spaces, such as functional and physical descriptions of the design, and hierarchical decompositions. Two tools that are useful in developing engineering systems are strategies for identifying and resolving engineering contradictions and methods for creating modular systems. Parallels between these concepts and their use in transdisciplinary research will be explored.

Functional Modeling

Formal methods used for representing functions during problem formulation describe a system's functions and how they interact [45, 46]. They are intended to facilitate communication among designers and stakeholders, build group consensus, and support the development of innovative and collaborative designs [47]. Problem formulation has been observed to be the most difficult task in design [28], and it is critical because design programs and designed artifacts will fail if problem formulation never stabilizes or is based upon incorrect premises. Recent research in engineering design has started with a "functional basis" for representing engineering designs, yet this is only one of many approaches to modeling functions that have been proposed [45, 46].

The approaches to representing functions can be divided into two categories: (1) "functional basis" or "black box" approaches that trace various flows through a system (typical examples include functional basis [34, 48-50], black box, and structured analysis and design technique (SADT) [44, 51-53]) and (2) those that alternate between functions and physical means, progressing from systems to components to create a hierarchy

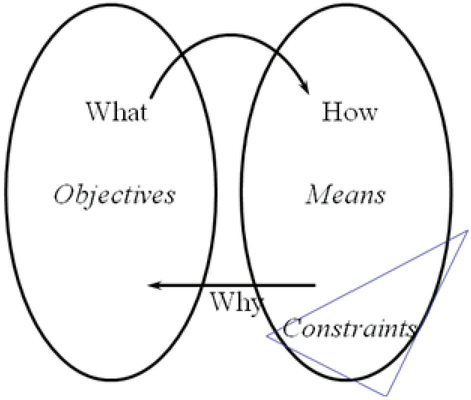

Figure 7.1 Domains.

of functions (for example, function means tree (FMT) [40, 41, 54-56] (compare with [57] and [28, 58]), enhanced FMT [59], Gero's function—behavior—structure (FBS) ontology [60-63], and SysML [64, 65]). Recent publications by Erdena et al. and van Eck et al. have compared and contrasted prominent approaches to functional modeling [66, 67].

Functional modeling can be helpful in clarifying the goals of a transdisciplinary research effort. In particular, functions can be stated using "solution-neutral language" [28] as desired transformations from an input state to an output state, independent of specific solutions. Additionally, functional basis methods can be used to map flows through relevant systems and are intended to provide a common language that can improve communication among team members [49].

Mapping

The design process can be defined as developing or selecting means to satisfy objectives, while being subject to constraints [68]. During the design process, the task that is being addressed can be divided into *domains* as shown in Figure 7.1. The nature of the design elements in each domain changes depending on the field of the problem. The domains consider the perspectives of the customer, functions, system, manufacturing process, etc. Design consists of a *mapping* between domains—what the designer wants to do and how he or she decides to do it. These domains can be in terms of function-behavior-structure, FRs and DPs, and customer expectations and engineering characteristics, etc., [28, 69-71]. The interactions between elements in different design domains is represented in terms of matrices of design relationships. These matrices capture relationship either for elements within one domain, such as the design structure matrix (DSM) [71, 72] (see also, [73]), or between elements such as the axiomatic design matrix [28, 58], the multiple-domain matrix [74], and the house of quality (HoQ) in quality function deployment (QFD) [70].

Similar to engineering design, transdisciplinary research also involves mapping across multiple domains. In transdisciplinary research, goals are mapped to the products of various disciplines. These could consist of theoretical concepts, models of various

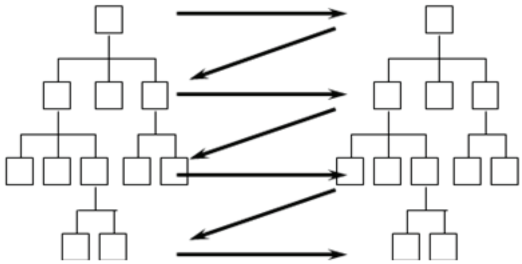

Figure 7.2 Hierarchies.

phenomena, methods or tools that comprise the discipline and theories that connect the theoretical concepts, models, and observed phenomena using the methods or tools.

Hierarchies

The design process progresses from a system level to levels of more detail [68]. The decisions about the product or system are structured a *hierarchical manner,* as shown in Figure 7.2, and hierarchies exist for any design object in each of the domains, including functional, physical, and process. Hierarchies of requirements, solutions, and constraints range from systems levels to levels of increasing detail, from systems to subsystems to assemblies to parts to part features to material properties. Domains, mapping, and hierarchies provide a structure for information about the design decisions that have been made. The framing of design tasks in this way enables the identification of general patterns in design decisions [28, 40, 50].

Many researchers in engineering design have used hierarchical structures to represent the flow of decision making in design, starting with Marples [57] and including function-means trees [40, 41, 54], axiomatic design [28, 58], and others.

Transdisciplinary research is inherently hierarchical. A large systemic problem is broken down into smaller pieces through mapping to various disciplinary pieces that are ultimately reintegrated into a new, holistic framework. Depending on the disciplines involved and the various elements that are adopted from each discipline, the smaller pieces are further decomposed until the researchers know what to do with them.

7.3.1.2 Tools

Engineering Contradictions

One criterion for choosing good engineering solutions is to choose solutions that minimize or eliminate system conflicts. *System conflicts* exist when attempts to improve some system attributes lead to the deterioration of other system attributes. A system conflict can be defined as (a) a useful action simultaneously causes a harmful effect, or (b) the introduction, or intensification, of a useful action or the elimination, or alleviation, of a harmful action causes an inadequacy or an unacceptable complication of one part or of the whole system. From a TRIZ standpoint, to make a good invention means to resolve a system conflict without compromise [36]. The existence of system conflicts has also been termed as a *coupled design* [28]. System conflicts can be at the level of engineering parameters such as a conflict between weight and strength, or power versus fuel consumption. They can also be manifest as physical contradictions such as the need to possess contradictory physical properties for different functional purposes, such as the need to have both large and small size.

Both axiomatic design and TRIZ provide tools for problem formulation that help identify areas within a system or design that have system conflicts or are functionally coupled. Within TRIZ are several algorithms, methods, principles, and examples for creatively modifying systems to eliminate conflicts [35-37]. Axiomatic design, provides both qualitative and quantitative approaches for assessing coupling to provide an objective means for identifying good design [28]. Some of these tools and techniques would be helpful in transdisciplinary research to identify the conflicts among different disciplinary goals, models, and perspectives. Moreover, they should help participants from multiple disciplines to reduce their "psychological inertia" [34] and create a common language for their problem in a "solution-neural environment" [28].

Modularity

A design can be arranged into different "chunks" or modules (groups of physical components) [71, 75]. *Modularity* is the use of standard parts or interfaces to provide flexibility and variety in meeting customer needs. According to Webster's dictionary, it is the use of "standardized units or dimensions" as a means for providing "flexibility or variety in use" [76]. Specifically, *flexibility* is defined as desired variety in inputs and outputs in performing functional requirements, and modularity is one strategy for providing this desired flexibility. The types of flexibility that are enabled by modular design include separate testing of functions, synthesis of products with custom functionality using new combinations of existing parts, and ease of product change. These benefits of modularity that are espoused by proponents do not correspond to a single uniform set of product characteristics: A wide range of possible benefits of modularity are given in [77] and [78], and Gershenson et al. give definitions and tools for modular design [79, 80].

Three types of modularity and associated metrics can be defined [68]: *Resource modularity* characterizes the ease of manufacturing or implementation; *operational modularity* characterizes the extent to which the users have options in the operation of the system; and *interfacial modularity* characterizes the amount of design effort embodied in an engineering change order (ECO). The first corresponds to the modularity of the design parameters, the second to the operation of the functional requirements, and the third to the modularity described within the design matrices that relate the functional requirements and design parameters.

In many situations modularity is a desirable characteristic from an engineering perspective. While the concept of separating problems into independent sub-tasks or problems is by definition antithetical to the transdisciplinary ethos, some of the concepts or measures of modularity may be useful to the transdisciplinary research community in either assessing the amount of integration needed for a particular problem or in more efficiently organizing research tasks and resource allocation. For example, Browning presents several uses of design structure matrices for structuring development activities, organizing development teams, or physically laying out systems [71, 81]. (See also [75]).

7.3..2 Theory of Technology Evolution

The above descriptions of engineering design processes can be combined with recent economics theories about technology development. Arthur states that the term technology as commonly used covers three distinct concepts. To clarify the differences, he looks at technology at three levels [82]:

1. The *technologies* embodied in a particular design
2. The *families of technologies* that comprise an engineering domain or discipline
3. A *technium,* which is technology as the whole "collection of devices and engineering practices available to a culture" at a time

Similarly transdisciplinary research efforts can be viewed in the context of the types of problems that are to be addressed:

1. The *integration of knowledge for a particular research topic*
2. Newly emerging *bodies of knowledge* that grow out of a community of researchers
3. The *sum of knowledge available to society* at one time

7.3..3 Mechanism for Dynamic Knowledge Integration

Specifically, the development of a new technology is "a [physical] phenomenon captured and put to use." This involves the combination of existing technologies. Arthur makes three claims about this evolution of technology [82]:

1. Novel technologies arise by combination of existing technologies.
2. "The stock of existing technologies must somehow provide the parts for combination. So the very cumulation of earlier technologies begets further cumulation....[T]herefore, existing technologies beget further technologies....These new technologies in time become possible components–building blocks–for the construction of further new technologies....The overall collection of technologies bootstraps itself upward from the few to the many and from the simple to the complex. We can say that technology creates itself out of itself."
3. Technology builds out of both combination of existing technologies and the constant capturing and harnessing of additional natural phenomena.

Taken together these three claims are used to build a theory of technology that explains its evolution: "Modern technology is not just a collection of more or less independent means of production. Rather it is becoming an open language for the creation of structures and functions in the economy. Slowly, at a pace measured in decades, we are shifting from technologies that produced fixed outcomes to technologies whose main character is that they can be combined and configured endlessly for fresh purposes" [82].

This explanatory mechanism can be applied to the transdisciplinary research process. Over time, efforts to address research topics expand from a focus on a particular system or situation under consideration to generating new bodies of knowledge that build upon each other and that continually integrate new discoveries, newly recognized physical phenomena, and new technologies. Transdisciplinary research seeks to integrate knowledge from existing disciplines in unique ways.

At the level of an individual research topic, it may be sufficient to bring together researchers representing multiple disciplines to investigate a common problem from diverse perspectives. If the results remain within the individual disciplinary frameworks, this would represent a multidisciplinary approach. Kollman and Ertas describe an example of designing a wind turbine as a collection of individual sub-systems: a structure designed by civil engineers, a gearbox designed by mechanical engineers, control systems and power transmissions designed by electrical engineers, etc. [14]. Many stakeholders may be represented in multidisciplinary efforts. If the system is free of system conflicts and coupling as described above, then modularization is possible. If so, tasks can be easily divided and work can be performed efficiently.

On the other hand, it is often desirable to consider the interfaces between the disciplines. In an example like the wind turbine design, changes that are made to the gearbox may make structural design or power generation easier [14]. In this case, interdisciplinary efforts are necessary. By working more closely together and explicitly considering the interfaces between modules and design activities, a more optimal solution can be obtained. As a result of this type of interaction, *new bodies of knowledge and new bodies of technology may develop***.** New knowledge is being generated that can later serve as a building block or stepping stone for further efforts.

The final stage of knowledge integration requires broadening perspectives even further. Such approaches to problem solving and technological system development consider areas far away from traditional disciplinary boundaries. In such cases, teams consider the social or environmental impacts of large-scale engineering or technical systems. Kollman and Ertas describe issues related to wide-spread use of wind power technology, including health effects from noise and vibration, visual impact on communities, effects on wildlife and bird migration, etc., [14]. These considerations would all normally be considered outside the bounds of an engineering problem. *Ultimately some problems require creative solutions that draw upon the sum of knowledge available to society at one time*—or may even be beyond the current scope of knowledge of society. In such cases, researchers and practitioners need very open and creative approaches to search for analogies among far-flung disciplines, technologies, and scientific phenomena. New approaches to identify relevant analogies among disciplines and apply them to engineering systems are needed.

7.3.3.1 Measures of Knowledge Integration

One premise of transdisciplinary research is that innovative ideas embody the novel combination of solutions that already exist separately in other designs and in other disciplines. This empirical observation has been made in the management and economics literature of innovation research [83]. It has also been used as part of the definition of level of invention provided by TRIZ in combination with the concept of resolution of system conflicts [36]. Adams and Tate have presented an approach to tie these observations to the engineering design of innovative designs, thus characterizing innovative designs according to their level of interdisciplinary and transdisciplinary combination of knowledge [84-86].

The quantification of transdisciplinary knowledge integration has been applied to design information embodied in patent documents. The inter- and transdisciplinary knowledge integration measures that Adams developed were constructed through the use of natural language processing, latent semantic analysis, and information retrieval techniques to build a data set of disciplinary functional and physical terms. The definitions of the measurements take into account the distribution of functions and solutions that comprise one design idea.

When considering the distribution of these functions and solutions that are described as subject–action–object (SAO) terms over many disciplines (in a general sense this can be n disciplines), some of the terms will be found only in one discipline. Others will be found in two disciplines, three disciplines, etc. up to terms that appear across all n disciplines. There are two types of knowledge integration that can be recognized in these terms. The first is typified by SAO terms that are used across n (or some subset of n) disciplines; this represents transdisciplinary knowledge. The other type of knowledge integration is typified by a design idea that contains SAO terms that are present previously in one discipline (that is mono-disciplinary functions and solutions) but that has synthesized a new integration of mono-disciplinary terms coming from what were previously n (or a subset of n) distinct disciplines. This type of knowledge integration can be considered as interdisciplinary knowledge integration.

7.3.4 Criteria for Assessing Transdisciplinary Research

Scientific and other intellectual theories comprise fundamental knowledge areas in the form of perceptions and understandings of different entities, and the relations between fundamental concepts. The fundamental concepts are at a more abstract level than observations of real-world data. These perceptions and relations are combined by researchers or practitioners to produce specific consequences, for example, predictions of events to be observed [39, 68].

7.3.4.1 Paradigms and Research Programs

The establishment of a disciple or transdiscipline can be distinguished by its paradigm or research program and its research community. According to Kuhn a *paradigm* for research is a unifying view of a discipline (“the entire constellation of beliefs, values, techniques, and so on shared by the members of a given [research] community” [87]) that is brought about *exemplars* (“the concrete puzzle-solutions which [are] employed as models or examples...as a basis for the solution of the remaining puzzles of normal science” [87]). Thus, for example, Newton’s *Principia* is a treatise which served as a unifying vision for the paradigm of Newtonian mechanics, and Dobzhansky’s *Genetics and the Origin of Species* provides an exemplar for the paradigm of neo-Darwinian biology. A research program can be defined as “a sequence of theories representing the development of a central idea” [88]. Similarly, a *research tradition* consists of “(1) a set of beliefs about what sorts of entities and processes make up the domain of inquiry; and (2) a set of epistemic and methodological norms about how the domain is to be investigated, how theories are to be tested, how data are to be collected, and the like” [89].

Therefore, a paradigm or a research program consists of four interrelated items [39, 68]:

- ontology: an identification of the fundamental concepts that make up the field of study
- aims: an articulation of the scope of the field in terms of both problems that have been solved (exemplars) and problems remaining to be solved (anomalies) which should be covered by the program—and are expected to be—but have not yet been
- methodology: guidelines for further developing the program—particularly in a manner consistent with the problem-solving approach that the program has been following
- theories: relationships between fundamental concepts of the field and application to specific problems

For transdisciplinary research, these items are not fixed. As Laudan indicates, paradigm change can be at many levels—ontology, methodology, or aims—and change can occur for one or more of these items at a time [90]. In the case of transdisciplinary efforts, a new research program is established in response to a particular situation or a particular need. Once the area of interest is determined and a multidisciplinary research team is established, in a transdisciplinary effort, the team has the flexibility to determine the aims of the project: What is to be addressed? What issues cannot be solved using current disciplinary approaches? Then concepts, methods, and theories from participating disciplines can be examined for relevance; terminology can be refined, redefined, or created; and a new *transdiscipline* can be established for that particular problem or project. If the same disciplines repeatedly work together and the scope and depth of collaboration increase, over time a *new body of knowledge* representing a new research tradition can gel.

7.3.4.2 Progressiveness

Tate and Nordlund provide a generic research program for design that describes data gathering, theory development, use of theories, and theory validation. [39] The criteria for choosing a research program are related to—but not synonymous with—the existence of *anomalies* or counterexamples. *Anomalies* are defined as “recalcitrant instances, not [as] refutations” [91]. Specifically, anomalies are identified with the expectation that they will be “solved” by the research program. The issue is whether the process of solving these anomalies is done in a manner consistent with the program’s heuristic—its program-specific set of problem-solving techniques [88]. As an example, for Newtonian mechanics, its heuristic consists of its mathematics: differential calculus, differential and integral equations, etc. [88]. Given that all theories have anomalies (according to Popper’s definition, they would be considered to be falsified), the quality may be judged according to the following criteria. A *progressive research program* meets three conditions [88]:

- Theoretically progressive condition: It must make new and interesting predictions, that is, “undreamed of” [88] by other programs. And these predictions are particularly good if they are counterexamples to rival research programs [91].
- Empirically progressive condition: Some of these predictions must be corroborated by the experimental evidence.

- Heuristically progressive condition: Furthermore, when anomalies are identified, the progressive program must be accommodating and explaining these anomalies in a manner consistent with the spirit of its heuristic—as opposed to in an ad hoc manner.

Transdisciplinary research efforts can be compared against these criteria. By definition they have a basis for comparison in their respective disciplines. So the criteria concern the relative merits of the transdisciplinary results compared with the disciplinary alternatives. Are the transdisciplinary theories able to explain and predict new phenomena that the old theories could not address? Do the results match the predictions? Is the research program making progress in way that is consistent with its heuristic? If so, the particular transdisciplinary approach is a success; if not, an alternative should be found. *Degenerating programs,* by definition, do not meet the above criteria.

7.4 Examples of Transdisciplinary Research in Engineering

Several recent research topics in engineering highlight cross-disciplinary knowledge transfer and transdisciplinary research approaches. These include sustainable design, biomimetic design, and engineering innovation.

7.4.1 Sustainable Design

Sustainable design can be defined as incorporating larger environmental, resource, and social issues into decisions of the conceptualization, design, manufacture, operation, and end-of-life of products and systems. These larger issues include, for example, environmental concerns, energy independence, and social impact. The sustainable design concepts and approaches should be driven by social and industrial needs while addressing forward-looking issues including the design and development of innovative products and service systems that use dramatically less energy, the provision of energy using "green" technologies, minimizing impact on the environment and biosphere, economic viability, and promotion of social well being for current and future generations. Efforts to teach sustainable design need to instill an appreciation for the innovation processes by which the sustainable designs can be adopted [92].

7.4.2 Biomimetic Design

Biomimetic systems design is the use of biological models to solve analogous engineering problems. Biological systems can provide stimulation for many various design objectives, including adaptability to changing environments, optimization, sustainability, repair, risk analysis, and remanufacture. Systematic methods and processes are proposed for engineers to access biological knowledge, identify analogical biological phenomena, comprehend material in the biological disciplines, choose one or more analogies, and apply analogical reasoning to create new knowledge.

Transdisciplinary research activities can progress through several levels of increasing scope of knowledge integration and collaboration. Biomimetic design is an example: it can be conducted at the level of an individual project—one engineering system or problem to be solved, such as mimicking the texture of shark skin or dynamic cross-section changes in wing profile—or it can be considered at the level of a growing body of knowledge that spans biology, mechanisms, materials, and controls. Most of the efforts in generic approaches to biomimetic design have been in the area of electro-mechanical systems and within the mechanical engineering community [93-96]. These efforts have not yet been integrated with computer science or software engineering to form the third level of transdisciplinary knowledge integration. There have been some efforts at mimicking for example, the human immune system for software intrusion detection, but these efforts have not joined with the efforts from mechanical disciplines.

7.4.3 Engineering Innovation

One research area in which the need for transdisciplinary approaches has been recognized is that of innovation. Recent publications and workshops have articulated the need for tighter integration between engineering design research and the study of innovation [97-99], the process by which technological changes are introduced and spread. "[I]nnovation in its broadest sense ... refer[s] to the entire process by which technological change is deployed in commercial products" [31]. Innovation is a broader activity than invention: "A technology may be invented, but it will not be an innovation until it is widely applied" [2].

No single discipline deals with all aspects of innovation; thus, there is a tendency towards cross-disciplinary research in the field. To get a comprehensive view, the insights from several disciplines must be combined [30]. Economics treats the innovation process as a "black box" and deals primarily with the allocation of resources to innovation and its economic effects. For example, economics studies the economic impact of technological change and how different nations or regions support or hinder innovative activity. Cognitive science and cognitive psychology investigate the creativity used and the learning that occurs in the process. Organizational settings are studied within sociology, organizational science, management, business, and social psychology. Economic geographers tie innovative learning processes to specific contexts or locales, which can change over time as explained in economic history. Finally history of technology investigates the links between the specific technology and the organization, economic, and social effects [30, 31].

7.5 Challenges and Opportunities

Sperber describes the challenges faced in interdisciplinary work and recognizes that current efforts do not go far enough in promoting understanding and cooperation between disciplines. While "grant proposals...have built in interdisciplinary rhetoric and describe future collaboration among people from different disciplines,...this is mostly done in order to meet the criteria for the grant. The actual scientific content generally consists in the juxtaposition of monodisciplinary projects with some effort to articulate their presentation." Sperber believes that the easiest way to have interdisciplinary work received is not to present it as such, but "to produce different versions of it for each of the disciplines concerned" [13].

Much of the difficulty of interdisciplinarity is due to the fact that attention, recognition, and authority are channeled by disciplinary institutions, yet researchers should recognize that "disciplines are artificial 'holding patterns' of inquiry whose metaphysical significance should not be overestimated." Researchers should not have a "providential view of the history of science [that] science is normally as it ought to be." This view "refuses to consider that science (or a particular science), had it pursued a different course of inquiry earlier in its history, would have ended up in a better epistemic position than it is in today. It simply take[s] for granted that [there could be no better outcome than that resulting from the choice] to dump Aristotle for Newton, Newton for Einstein, etc.–and at roughly the times and for the reasons they were dumped" [100].

The prospect of transdisciplinary research is exciting. The growth of globalization, cyberinfrastructure, and other enabling technologies should facilitate broader participation in research and innovation activities. New networks of researchers can be created in a short time, and other non-traditional participants can become involved in solving the world's problems. Whenever invention or innovation occurs, someone has recognized a need and acted upon it. The inventor or innovator identified shortcoming with existing designs, systems, technologies, theories, etc. and acted upon that insight [101]. Imagine the what-if scenario in which individuals around the world recognize needs in their own communities and have access to the engineering, science—even transdisciplinary research—and build new knowledge to realize their visions for solutions.

7.6 Conclusions

This paper has presented challenges faced due to rapidly accelerating technological development and the need for a transdisciplinary approach to engineering systems. The focus of the paper was on drawing an analogy between transdisciplinary research and theories of engineering design and technological system development. The analogies were used to propose a mechanism for dynamic knowledge integration using transdisciplinary approaches based on a three-level progression of the scope of transdisciplinary research activities. Concepts and tools from engineering design and innovation were used to explain challenges and opportunities for the future of transdisciplinary research, and preliminary measures for transdisciplinary and interdisciplinary knowledge integration were discussed. Validation of transdisciplinary research was presented in light of approaches to philosophy of science and the sociology of intellectual discourse. Finally examples of transdisciplinary research areas that combine engineering design with other fields such as sustainability, biology, and management of technology were given.

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8 Deciphering Interdisciplinary and Transdisciplinary Contributions

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Abstract

The incapacity of many human societies to deal with contemporary environmental questions (such as climate change, health epidemics, land-use, forestry management, renewable and non-renewable resources, housing, poverty, and urban planning) can be contrasted with the viewpoint of many professionals and politicians who are convinced that they have the "right answers." However, the lack of consensus about climate change, the stock of renewable and non-renewable resources, and the failure of so-called "model" housing estates and urban planning projects constructed since the 1950s in countries with socialist or free-market economies clearly show that new ideas, working methods, objectives, and criteria are needed in both scientific research and professional practice. The challenges related to dealing with the above-mentioned problems concern their complexity, the compartmentalization of scientific and professional knowledge, the sector-based division of responsibilities in contemporary society, and the increasingly diverse nature of the societal contexts in which people live. In addition, the lack of effective collaboration between scientists, professionals, and policy decision-makers has led to the "applicability gap" in sectors that deal with both the natural and human-made environment. This chapter discusses the added value of interdisciplinary and transdisciplinary contributions as well as the challenges that are commonly confronted by those who wish to implement them to deal with complex real-world issues.

8.1 Introduction

Today there is no consensual definition of interdisciplinary and transdisciplinary contributions. Current confusion and misunderstandings about multidisciplinary, interdisciplinary, and transdisciplinary contributions to scientific research, formal education programmes, and professional practice have a history that can be traced back at least to the seminar organized by the Organization for Economic Co-operation and Development (OECD) in 1970. In some of the papers presented at that seminar, a distinction was made between interdisciplinary and transdisciplinary contributions [1]. Both Erich Jantsch, the Austrian physicist, and Jean Piaget, the Swiss psychologist, adopted an interpretation that refers to systems theories and a multi-level or hierarchical model that positions multidisciplinary contributions below interdisciplinary ones, which, in turn, are below transdisciplinary contributions. Jantsch and Piaget agree that multidisciplinary approaches merely juxtapose different disciplinary contributions whereas interdisciplinary approaches are coordinated and integrated. Accordingly, transdisciplinary approaches combine more disciplinary contributions in order to generate a more comprehensive level of understanding by applying an enlarged systemic framework of several disciplinary and interdisciplinary contributions.

Thirty years after the international seminar organized by the OECD, a consortium of Swiss academic and professional institutions organized an international conference in Zurich in 2000.

About 800 participants from 50 countries attended, and they were presented with different interpretations of interdisciplinary and transdisciplinary approaches compared to those of the 1970s [2]. In particular, transdisciplinary approaches were considered new forms of learning and problem solving that involve actors from both the scientific community and other sectors of civil society (non-governmental organizations, community associations, and the private sector) in order to tackle real-world problems. This interpretation is not the same as the enlarged application of disciplinary approaches that was proposed in the 1970s.

Some reasons for the shift in the interpretation of interdisciplinary and transdisciplinary approaches between 1970 and 2000 are grounded in the ability of scientific research to deal with tangible research questions that societies need to tackle. These include public health challenges, such as the obesity epidemic; impacts of global change, including the effects of desertification on natural and human-made ecosystems; and the consequences of the uses of different kinds of energy resources on local and global economies. Another concern has been related to the complexity of these real-world issues and the incapacity of any one discipline or profession to deal with them effectively. Gibbons et al. argued that the conventional modes of doing scientific research are insufficient and that joint problem solving among science, technology, and representatives of civic society are essential [3]. Hence, in contrast to other interpretations, the International Conference in Zurich provided an innovative framework for participatory research on a wide range of real-world problems rather than focusing only on academic research and the curricula of higher education programmes.

Today there is no shared definition of interdisciplinary and transdisciplinary contributions. Nonetheless, it is more widely accepted that transdisciplinary approaches are not synonymous with interdisciplinary ones. However, there is still no consensus concerning the differences between interdisciplinary and transdisciplinary contributions [4].

The relationship between researchers in different disciplines, especially in the human/social and the basic/natural sciences, is often considered to be a source of conflict.

Yet, this need not be the case as Boyden and his colleagues showed more than 20 years ago in their applied human ecology research about Hong Kong [5]. Innovative contributions of this kind can lead to the development of new terminology, innovative concepts, and new knowledge. This is an important challenge for those who wish to apply interdisciplinary or transdisciplinary approaches to deal with complex environmental questions.

When dealing with complex subjects, such as core environmental questions, it is necessary to shift from mono-disciplinary to interdisciplinary and transdisciplinary concepts and methods. In order to be effective, this shift should be founded on a clarification of definitions, goals, and methods. In this paper, disciplinarity refers to the specialization and fragmentation of academic disciplines especially since the 19th century. Each discipline has its own concepts, definitions, and methodological protocols for the study of its precisely defined domain of competence. Multi-disciplinary refers to an additive research agenda in which each researcher remains within his or her discipline and applies its concepts and methods without necessarily sharing a common goal with other researchers. Interdisciplinary studies are those in which concerted action and integration are accepted by researchers in different disciplines as a means to achieve a shared goal that usually is a common subject of study. In contrast, transdisciplinary contributions incorporate a combination of concepts and knowledge not only used by academics and researchers but also other actors in civic society, including representatives of the private sector, public administrators, and the public. These contributions enable the cross-fertilisation of knowledge and experiences from diverse groups of people that can promote an enlarged vision of a subject, as well as new explanatory theories. Rather than being an end in itself, this kind of research is a way of achieving innovative goals, enriched understanding, and a synergy of new methods.

Multidisciplinarity, interdisciplinarity, and transdisciplinarity are complementary rather than being mutually exclusive. Both interdisciplinary and transdisciplinary research and practice require a common conceptual framework and analytical methods based on shared terminology, mental images, and common goals. Without specialised disciplinary studies, there would be no in-depth knowledge and data. This paper will summarize the mainstream interpretations of interdisciplinary and transdisciplinary contributions and illustrate them with respect to recent publications in the field of environmental studies.

What is interdisciplinarity?

It is generally accepted that interdisciplinary contributions involve the collaboration and cooperation of scientists from at least two disciplines who apply their disciplinary competence to work on common questions and the achievement of shared results. The core characteristic of interdisciplinary approaches is their goal to integrate concepts, methods, and principles from different disciplines.

What is transdisciplinarity?

Transdisciplinarity is an ambiguous term that has been interpreted in various ways. Balsiger noted that there is no complete history of this term or concept. Like interdisciplinarity, there seems to be no consensus about its meaning. This being said, several shared aims of transdisciplinarity can be identified by an analysis of recent publications.

First, transdisciplinarity admits and confronts complexity in science and it challenges knowledge fragmentation [8]. It deals with research problems and organizations that are defined from complex and heterogeneous domains such as global environmental change or public health challenges [9]. As well as complexity and heterogeneity, this mode of knowledge production is also characterized by its hybrid nature, non-linearity, and reflexivity, transcending any academic disciplinary structure [10].

Second, transdisciplinary research accepts local contexts and uncertainty. It is a context-specific negotiation of knowledge [11]. Third, transdisciplinarity implies intercommunicative action. Transdisciplinary knowledge is the result of inter-subjectivity [12]. It is a research process that includes the practical reasoning of individuals with the constraining and complex nature of social, organizational, and material contexts. For this reason, transdisciplinary research and practice require close and continuous collaboration during all phases of a research project or the implementation of a project.

Fourth, transdisciplinary research is often action-oriented. It entails making linkages not only across disciplinary boundaries but also between theoretical development and professional practice [13]. Transdisciplinary contributions frequently deal with real-world topics and generate knowledge that not only address societal problems but also contribute to their solution [14]. One of its aims is to understand the actual world and to bridge the gap between knowledge derived from research and decision-making processes in democratic societies. However, transdisciplinary research should not be restricted to applied knowledge [15]. This common interpretation is too restrictive because there is no inherent reason why theoretical development - especially the analytical description and interpretation of complex environmental questions - cannot be achieved by transdisciplinarity. This is a basic necessity if advances are to be made in research and practice about real-world issues.

8.2 Understanding Multidisciplinary, Interdisciplinary, and Trandisciplinary Contributions

Although interdisciplinarity and transdisciplinarity have been used interchangeably by some authors, the difference between multidisciplinary, interdisciplinary, and transdisciplinary contributions will now be summarized.

Bruce et al. stated that in multidisciplinary research, each discipline works in a self-contained manner and that in interdisciplinary research, an issue is approached from a range of disciplinary perspectives integrated to provide a systemic outcome [16]. In transdisciplinary research, however, they affirm that the focus is on the organization of knowledge around complex heterogeneous domains rather than the disciplines and subjects into which knowledge is commonly organized.

Some authors remind us that the word interdisciplinary has been used consistently to denote scientific research that involves a number of disciplines [17]. In contrast, the word transdisciplinary has not been restricted to scientific research. It has been used since the 1970s in debates about teaching that were launched by the famous Swiss psychologist Jean Piaget, as well as in the practice of architecture, urban design, and land-use planning that involves stakeholders in decision-making processes.

Ramadier argued that transdisciplinarity should not simplify reality by only dealing with parts of it that are compatible at the crossing of multiple disciplinary perspectives, as is often the case with interdisciplinary research [18]. He introduced the argument that transdisciplinarity is at once between disciplines, across disciplines, and beyond any discipline, thus combining and going beyond all the processes of multidisciplinarity and interdisciplinarity. He stressed that transdisciplinary approaches can only be effective if there is a significant shift in disciplinary thinking. He argued this would involve a shift from disciplinary divisions (which search for the unity of knowledge) to collaborative deconstruction (which seeks coherence).

Ramadier illustrates these approaches by the study of people-environment relations in urban areas. He considers the contributions of scholars in anthropology, architecture, history, human geography, urban sociology, and psychology. Each of these disciplinary contributions includes concepts and methods that are applied to study people in precise situations, usually only at one point in time. He then discusses how disciplinary interpretations of the legibility of urban space have not provided innovative knowledge. In contrast, he notes that transdisciplinary contributions by some environmental psychologists have led to the formulation and validation of innovative concepts, such as place identity. Since the 1970s, the concept of place-identity has provided important contributions to the field of architecture, human geography, psychology, and sociology by showing the influence of the physical environment on identity and self-perception.

Després, Brais, and Avellan describe the context, theoretical framework, methodology, and results of a collaborative urban planning project to redefine the future of suburban neighborhoods built between 1950 and 1975 on the outskirts of Quebec City in Canada [19]. The authors stress that transdisciplinarity and intersubjectivity explicitly form the theoretical and methodological foundations of their work. They adopt a framework stemming from the theory of communicative action by the German philosopher Jürgen Habermas. The authors share Habermas' conviction that scientific knowledge is not the only type of rational knowledge and that instrumental, ethical, and aesthetic knowledge should be integrated to form a holistic science [20]. They endorse Habermas' position that rational knowledge is not only defined by what is known but also by how it is communicated. Dialogue processes, mediation, negotiation, and consensus building are means for the development of mutual understanding and intersubjectivity that, in turn, produce a fifth type of hybrid knowledge.

Després and her colleagues applied this theoretical framework and developed a methodology that combines scientific analysis, action research, and participatory design processes. The successive phases of their work involve a diagnostic of the demographic, environmental, physical, and social characteristics of suburban environments; the definition of objectives and criteria for the revitalization of specific suburbs; and the development of an architectural and urban design project for the redevelopment of these suburbs using an 18-month participatory process with stakeholders and representatives of the local population.

Transdisciplinary contributions of this kind enable the cross-fertilisation of ideas and knowledge from different contributors that promotes an enlarged vision of a subject, as well as new explanatory theories. Innovative contributions require not only logical reasoning but also imaginative thinking [21]. Transdisciplinarity is a way of achieving innovative goals, enriched understanding, and a synergy of new methods.

Several recent contributions propose that the difference between interdisciplinary and transdisciplinary contributions stems from the latin prefix "trans," which denotes transgressing the boundaries defined by traditional disciplinary modes of inquiry. They make a distinction between the research group, which will always remain interdisciplinary by the very nature of disciplinary education and inquiry in general, which, if transdisciplinary, implies that the final knowledge is more than the sum of its disciplinary components. Lawrence compares interdisciplinary approaches to a mixing of disciplines while transdisciplinary ones would have more to do with a fusion of disciplinary and other kinds of knowledge [22]. This interpretation means that transdisciplinarity is not an automated process that stems from the bringing together of people from different disciplines or professions. In addition, it requires an ingredient that some have called transcendence [23]. This implies the giving up of sovereignty over knowledge, the generation of new insight and knowledge by collaboration, and the capacity to consider the know-how of professionals and lay-people.

Wiesmann and his colleagues summarize the dominant interpretation of transdisciplinarity in German-speaking countries of Europe as "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" [24].

This paper shows that the debate about the "correct" definition of interdisciplinary and transdisciplinary research has been a continuous one since the 1970s. Here it is important to emphasize that multidisciplinarity, interdisciplinarity, and transdisciplinarity approaches are better treated as complementary rather than being mutually exclusive. It is important to stress this complementarity because the interrelations between these approaches ought to be more systematic than they have been in recent years.

8.3 Conclusion

There is an urgent need for innovative approaches in many situations, such as the blatant failure of the wealthiest countries of the world to deal with a wide range of challenges. For example, the necessity of addressing environmental concerns has not been recognized by all actors and institutions in developed and so-called developing countries as being essential for sustaining human living conditions on earth. Many governments in these countries have not realized the urgency of mitigating the consequences of their ways of life by the implementation of innovative policies. This inertia has some of its origins in the lack of interdisciplinary and transdisciplinary contributions. Most scientific contributions on this subject are completed by the bio-physical environmental sciences in order to understand the changes and impacts in the bio-physical environment. Nevertheless, analyses of the behaviour and organization of human societies are also needed to address the situation with political tools. Therefore, at the very least, multidisciplinarity is required to address this complex issue in its globality. However, the different epistemologies of each discipline and science (in both the natural and human sciences) raise difficulties for collaboration, preventing strong interdisciplinarity, especially when treated within traditional disciplinary scientific methodological frameworks. The practical solution will lie in the capacity of teams of researchers and representatives of civil society to join their research objectives by building dialogue. However, even as many researchers and practitioners no longer question the need for interdisciplinary contributions, transdisciplinary approaches are still not yet commonly applied in order to address core environmental questions.

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

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Abstract

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

9.1 Introduction

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

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

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

9.2 Defining the Challenge

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

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

This planet is becoming increasingly interconnected as new opportunities and highly complex problems tie us to the rest of the world in ways we are only beginning to understand. When we 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 [2]. One of the largest public health issues of our time is the world water crisis. Nearly 2.5 billion people (roughly 2/5ths of the world's population) lack access to safe drinking water and sanitation [3].

A rising tsunami of energy problems is beginning to endanger the economy of the world and human living conditions. Finally, issues related to transportation, humanitar-

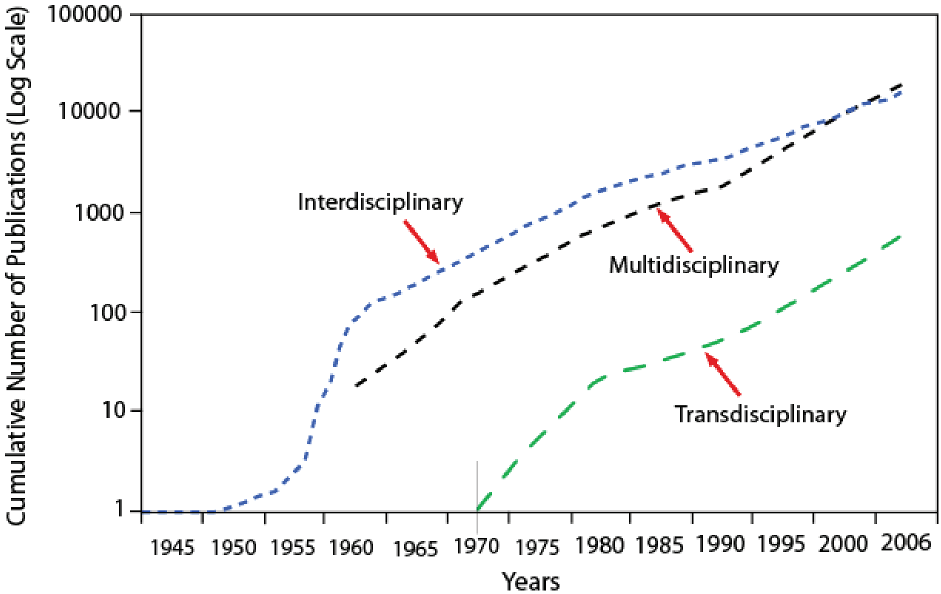

Figure 9.1 Web of Science Citations for Multi-, Inter- and Transdisciplinary Research.

ian needs, security, natural disasters, health, international development, ethnic violence and terrorism, military conflict, and emergency response are among the many global complex problems facing mankind in the 21st century. There is a need for transdisciplinary research to tackle the ill-defined problems of this century. Many distinguished researchers and educators contributed for the development of transdisciplinary education and research concepts [1, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17].

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

9.3 Comparison of Interdisciplinary and Transdisciplinary Research

The history of the term "Interdisciplinary" goes back to 1944 when it was used for the first time in the literature. Being a relatively new term, "transdisciplinary" first appeared in 1970. As seen from Figure 9.1, the most commonly used term "Multidisciplinary" has had over 18,000 citations by the year 2006 [18].

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

Després et al. stated that the difference between interdisciplinary and transdisciplinary contributions stems from the Latin prefix "trans" which denotes transgressing the boundaries. When the transdisciplinary approach is used, the final knowledge generated is more than the sum of the collaborating diverse discipline components [19].

Lawrence compares interdisciplinary research approaches to a "mixing of disciplines," while transdisciplinary ones would have more to do with a "fusion of disciplines" [20].

Ramadier commented that interdisciplinarity is sufficient for the purpose of seeking coherence between different forms of knowledge produced by diverse disciplines. He also stated that interdisciplinarity plays a role in the simplification of knowledge [21].

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

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

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

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

While the transdisciplinary research approach, in theory, should lead to better research progress, it will not solve the problems and challenges mentioned above. The transdisciplinary research approach also has potential disadvantages [22]. Among them:

- The research budget will be potentially higher since the transdisciplinary research team involves a greater number of researchers;

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

Evaluation of interdisciplinary and transdisciplinary research has been discussed by many researchers [23, 24, 25, 26]. The contexts, methodologies, and conceptual framework of interdisciplinary and transdisciplinary research varies greatly. Seven generic principles have been proposed to evaluate the interdisciplinary and transdisciplinary research [27].

They are:

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

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

Question-1

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

Interdisciplinary research process

Not Very   Somewhat   Very

Transdisciplinary research process

Not Very   Somewhat   Very

Question-2

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

Interdisciplinary research process

Not Very   Somewhat Very

Transdisciplinary research process

Not Very   Somewhat   Very

Question-3

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

---------Interdisciplinary research process

---------Transdisciplinary research process

9.4 Survey Analysis

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

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

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

$$\begin{aligned}&(\overline{x}_1 - \overline{x}_2) - t_{\alpha/2, n_1+n_2-2} S_p \sqrt{1/n_1 + 1/n_2} \le (\mu_1 - \mu_2) \\ &\le (\overline{x}_1 - \overline{x}_2) + t_{\alpha/2, n_1+n_2-2} S_p \sqrt{1/n_1 + 1/n_2}\end{aligned} \tag{2}$$

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

9.4.1 Data Analysis and Results

A survey on transdisciplinary education was conducted starting in June, 2009 for five weeks. With over 134 responses, the data provides an abundance of useful information on transdisciplinary and interdisciplinary activities. Results of the survey by groups are shown in Table 9.1. The survey was divided into four groups. They are researchers, academics, industry/business, and graduates. The graduates from the Transdisciplinary Masters of Engineering were also included in one of the groups in the survey. The sur-

Table 9.1 Summary of Survey Responses.

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

veys were sent to individuals from all areas of the world who had some experience or education in either interdisciplinary or transdisciplinary research and education. Some of the results were about what we expected, and only a very few of them surprised us. Response rate for the survey was better than expected. Total response rate was 53.6%, while in every category the response rate reaches to at least 45.9%.

Interdisciplinary and Transdisciplinary Research Processes Comparison (Group: Researchers):

For this group survey results are given in Table 9-A in the Appendix A. Using values from this table, the pooled estimator for *question-1* can be calculated as

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

Then

$$S_p = 0.776$$

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

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

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

Rearranging yields

$$-0.922 \le \mu_1 - \mu_2 \le -0.078$$

Note that finding $t_{\alpha/2, n_1+n_2-2} = 1.96$ from the *t* distribution table the degree of freedom is taken to be *df* =26+26-2=50 and $\alpha / 2 = 0.025$. After performing same calculations for the quations #2 and #3, summary of the results are presented in Table 9.2.

Table 9.2 Summary of Calculations for Interdisciplinary and Transdisciplinary Researc Process Comparison (Group: Researchers).

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

For the researchers group, 26 sample data were analyzed. Table 9.2 shows that there is a statistical difference for questions 1 and 3 (confidence interval does not inclu de $(\mu_1 - \mu_2) = 0$ at the 95% level of confidence in two means). By checking means of both research processes ($\bar{x}_1$ being the mean of interdisciplinary and $\bar{x}_2$ being the mean for transdisciplinary), we can conclude that the transdisciplinary research process requires better research project organization, managing and coaching than the interdisciplinary research process. Also the transdisciplinary research process provides better quality of integrative research outcome to solve complex problems than the interdisciplinary research process.

As seen from Table 9.2, for question 2 confidence interval includes $(\mu_1 - \mu_2) = 0$ therefore it is concluded that there is no statistical difference at the 95% (two sided) level of confidence in two means. It turns out that development of sustained collaboration is necessary for both transdisciplinary research process and interdisciplinary research process.

Using randomly selected 28 samples, similar survey analysis were performed for academics, industry/business, and graduates groups and the results of analysis are shown in Tables 9.3, 9.4 and 9.5.

By reviewing Tables 9.3, 9.4 and 9.5 we conclude that outcome of the survey results from academics, business/industry, and graduates turn out to be exactly same. In other words;

Table 9.3 Summary of Calculations for Interdisciplinary and Transdisciplinary Research Process Comparison (Group: Academics).

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

Table 9.4 Summary of Calculations for Interdisciplinary and Transdisciplinary Research Process Comparison (Group: Business/Industry).

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

Table 9.5 Summary of Calculations for Interdisciplinary and Transdisciplinary Research Process Comparison (Group: Graduates).

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

- Research project organization, managing, coaching, and development of sustained collaboration are more needed for the transdisciplinary research process than the interdisciplinary research process.
- Development of sustained collaboration is necessary for the transdisciplinary research process more than the interdisciplinary research process.
- Transdisciplinary research process does provide better quality research outcome than the interdisciplinary research process.

9.5 Conclusions

Over the last six decades the integration of research methods and techniques across the disciplines has changed rapidly. 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. Because disciplines inevitably develop into self–contained shells, interaction with other disciplines is minimized. However, practitioners of a discipline develop effective intra–disciplinary communication based on their disciplinary vocabulary.

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

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

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

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APPENDIX-A

Table 9-A

Question #1

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

Question #2

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

Question #3

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

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