



Transdisciplinary Trans-Sector Integration in Education: Convergence

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This paper examines A-STEM-H (Art & Science, Technology, Engineering, Math and Humanities) Transdisciplinary Domain – teaches students new skills aimed at creativity, innovation, and working across knowledge fields; offers an approach that synthesizes methodologies from multiple fields; teaches the ability to collaborate across multiple spheres of knowledge and practice; prepares students to design, develop, and deliver a system that qualifies a student to be workforce ready.

This paper also proposes a unique transdisciplinary Ph.D. program and curriculum representing eight main sector activities selected from primary, secondary and tertiary (service) sectors in the United States which impacts the global economy.

Keywords: A-STEM-H, transdisciplinary domain, trans-sector, transdisciplinary curriculum.

1 Introduction

Transdisciplinarity can be defined as the practice of acquiring new knowledge through education, re-

search, design, and production with a broad emphasis on complex problem solving. The goal of transdisciplinary practice is to improve students' understanding of complex issues by extracting the valuable aspects of typical academic disciplines and thereby generating both a more integrative and universal solution to support an issue of importance to society (Ertas et al., [1]).

An interdisciplinary (ID) methodology has been defined as “two or more disciplines which combine their expertise to jointly address an area of common concern” (Ertas et al., [2], Devlin, [3]). “Interdisciplinary approaches integrate separate disciplinary data, methods, tools, concepts, and theories in order to create a holistic view or common understanding of complex issues whereas transdisciplinary approaches are comprehensive frameworks that transcend the narrow scope of disciplinary world views through an overarching synthesis (Klein, [4])”. Transdisciplinary (TD) research includes cooperation within the scientific community and a debate between research and society at large. TD research therefore transgresses boundaries among scientific disciplines and between science and other fields and includes deliberation

about facts, practices and values (Hadorn et al., [5]).

“Convergence: facilitating transdisciplinary integration of life sciences, physical sciences, engineering, and beyond is an approach to problem solving that cuts across disciplinary boundaries. It integrates knowledge, tools, and ways of thinking from life and health sciences, physical, mathematical, and computational sciences, engineering disciplines, and beyond to form a comprehensive synthetic framework for tackling scientific and societal challenges that exist at the interfaces of multiple fields. By merging these diverse areas of expertise in a network of partnerships, convergence stimulates innovation from basic science discovery to translational application. It provides fertile ground for new collaborations that engage stakeholders and partners not only from academia, but also from national laboratories, industry, clinical settings, and funding bodies. (National Research Council of the National Academies, [6])”

The expected results of TD research and education are: emphasis on teamwork; bringing together non-academic experts and academic researchers 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 TD approach teaches students 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.

2 Need for Transdisciplinary Graduate Education

“If the world of working and living relies on collaboration, creativity, definition and framing of problems and if it requires dealing with uncertainty, change, and intelligence that is distributed across cultures, disciplines, and tools—then graduate programs should foster transdisciplinary competencies that prepare students for having meaningful and productive lives in such a world,” (Derry and Fischer, [7]).

Graduate education today is experiencing a period of profound transformation. Phenomena such as the information technology revolution and globalization (National-Research-Council, [8]), globalization (Friedman, [9]), growing trends to outsource high-level cognitive tasks (Aspray, Mayadas, & Vardi, [10]; Levy & Murnane, [11]), and the need to contribute successfully in diverse collaborative organizations addressing today's complex world problems (Brown & Duguid, [12]) are changing goals of the graduate education (Derry and Fischer, [7]).

Requirements have changed over the years for Ph.D. graduates to enter work settings requiring collaboration with experts from multiple fields, pursue several career paths tackling different problems, and to interact and work with people of diverse backgrounds including experts those from outside academe (Derry and Fischer [7], Golde, [13]; Panofsky & Rhoten, [14]). Such changes create new educational requirements: graduate students would greatly enhance their skills and employment opportunities if they were able to master TD competencies before they go on to employment.

Transdisciplinary can help in making creativity more evident in the teaching and research activities of universities (McWilliam et al., [15]). “The increasing understanding of the importance of technological innovation to economic competitiveness is challenging a new pressure for engineering education and research at the extremely difficult technical, medical, social, and cultural problems. Scarcity of knowledge base to solve these problems is becoming more and more predominant. Therefore, engineering education must produce highly qualified, well-trained engineers who can interface with other sectors of society to address complex problems require many activities which cross discipline boundaries,” (Ertas et al., [16]).

Several academic institutions in globe already have set up programs to support TD research and education. Cronin stated that “There is a need for transdisciplinary research (TR) when knowledge about a societally relevant problem field is uncertain, when the concrete nature of problems is disputed, and when there is a great deal at stake for those concerned by problems and involved in dealing with them. TR deals with problem fields in such a way that it can: a) grasp the complexity of problems, b) take into account the diversity of life world and scientific perceptions of problems, c) link abstract and

case specific knowledge and d) constitute knowledge and practices that promote what is conceived to be the common good.” (Cronin, [17]).

Since 2005, Transdisciplinary Studies Program at Claremont Graduate University have offered over 80 transdisciplinary courses. These courses introduce students to the practices of transdisciplinary study and foster collaborations across disciplines and schools that would not necessarily occur in traditional single-discipline courses [18].

The Center Leo Apostel (CLEA) was created in 1995 as a transdisciplinary research department. The center’s goal is the development of world views that integrate the results of different scientific and cultural disciplines. Crossing the boundaries of natural sciences, the social sciences, and humanities for knowledge generation is the main objective of CLEA [19].

Network for Transdisciplinary Research (td-net) was created in 2000 by the Swiss Academic Society for Environmental Research and Ecology (SAGUF) and taken over by the Swiss Academy of Sciences (SCNAT) in 2003. Since 2008, the td-net for transdisciplinary research has been a project of the Swiss Academies of Arts and Sciences.

The National Cancer Institute (NCI) was authorized by NIH as the first institute for transdisciplinary approach to health research. Its Transdisciplinary Tobacco Use Research Center (TTURC) initiative was initiated in 1999 and three center programs followed in the early 2000s: the Centers of Excellence in Cancer Communication (CECCR) and Centers for Population Health and Health Disparities (CPHHD) in 2003 and Transdisciplinary Research in Energetics and Cancer (TREC) centers in 2004. These research centers across the United States are developing and translating scientific knowledge and discoveries into new treatments for cancer patients.

Recently, a 13.5 million dollar grant has been awarded jointly to the University of Minnesota and the University of Alabama, Birmingham, to initiate the National Transdisciplinary Collaborative Center for African American Men’s Health (NTCC). This funding is provided by the National Institutes for Health’s National Institute on Minority Health and Health Disparities. The grant started on July 1, 2013, and will fund five years of activity for the center [20].

A report presented to the Texas Higher Education Coordinating Board by the Graduate Education Ad-

visory Committee (GEAC), in July 2, 2009 states that “the research and education at Texas universities must continue to work at the transdisciplinary frontiers of knowledge, and that work will require collaboration throughout the state, not only among various disciplines, researchers, and institutions but also with local businesses and governments” Three critical success factors for global Competitiveness out of eleven were related to transdisciplinarity [21]:

- Number of interdisciplinary or transdisciplinary funded research collaborations within a university,
- Number of interdisciplinary or transdisciplinary funded research collaborations among universities, and
- Number of new transdisciplinary programs

Challenging technical, medical, social, and cultural issues and the complex nature of community and world problems has intensified the need to provide students with an education that enables them to work on a wide range of topics emphasizing on collaboration, cross-discipline team based research and development of habits for life-long learning. To meet this need, in 2007, after graduating 126 MS students; upon Raytheon’s management request very successful Transdisciplinary Master’s program was expanded to a Transdisciplinary PhD program (Ertas et. al., [1]). So far, more than 50 Ph.D. students have enrolled to this program.

Transdisciplinary research and education could initiate many breakthroughs that improve lives and strengthen the economy, however cultural and institutional barriers interfere with its development. In spite of these difficulties, we have established a unique and vital on-campus Transdisciplinary PhD Program focus on a Design, Process, and Systems track that is offered by the Mechanical Engineering Department at Texas Tech University. A systems approach of this Ph.D. program considers research projects on Art & Science, Technology, Engineering, Math and Humanities (A-STEM-H).

Many other universities have developed transdisciplinary studies around the world. Some of them are: Graduate School Frontier Science-The University of Tokyo, The Graduate School of the University of North Carolina at Chapel Hill, University of Wisconsin-Madison, Burnham Institute for Medical Research, New York University, The Virginia Bioin-

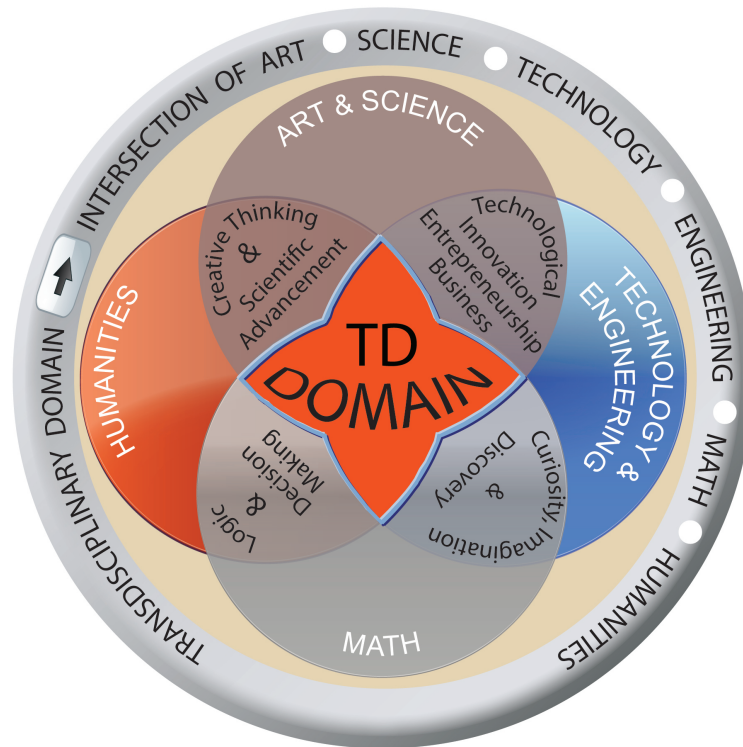


Figure 1: A-STEM-H Transdisciplinary Domain.

formatic Institute at Virginia Tech, Salve Regina University, Woodbury University, University of Calgary Transdisciplinary Colleg, Brown University, University of Colorado-Boulder, CINII- National Institute of Informatics, University of Southern Queensland, University of California, San Francisco, Transdisciplinary Educational Achievements in Romania, The University of Vermont, Arizona State University School of Sustainability, University of Stellenbosch University and Korea Institute for Advanced Study (ATLAS, [22]).

2.1 A-STEM-H Transdisciplinary Domain

Figure 1 describes the attempt to integrate arts and humanities into STEM education. A-STEM-H is not only just science, technology, engineering, and math education – It is a Transdisciplinary applied approach that is linked with real-world problem based learning. Connections between STEM and sister disciplines such as art and humanities occur at the boundary of the Transdisciplinary domain – intersection of art and science, technology, engineering, math and humanities. The six discrete disciplines are not anymore separate but “interconnected” through an acronym, A-STEM-H. Interconnection between

disciplines goes beyond integration. A-STEM-H is a system of interconnected disciplines without boundaries within the TD domain which creates a cohesive teaching and learning paradigm. Transdisciplinary A-STEM-H integrates knowledge, tools, methods, and cognitive thinking skills from a wide diversity of fields to form an inclusive framework to solve challenging complex contemporary social issues that exist at the interfaces of multiple disciplines.

Using system analogies, we can conclude for important characteristics of A-STEM-H as:

- All six disciplines of A-STEM-H interact with and rely on one another simply by the fact that they occupy the same Transdisciplinary Domain – Interconnectivity.
- All six disciplines of A-STEM-H, which interact with one another within the TD Domain and cannot be analyzed as transdisciplinarity if considered alone.
- A-STEM-H provides an educational capability that is greater than the sum of the contributing disciplines.

Unique contributions of the humanities to A-STEM-H education may be considered as follows

(Donnelly, [23]).

- an appeal to an autonomous self with the right and capacity to make independent decisions and interpretations;
- indeterminacy in the subject matter of these decisions and interpretations;
- a focus on meaning, in the context of human responses, actions, and relationships, and particularly on the ethical, aesthetic, and purposive; and
- the possibility of cohesion in standards of decisions and interpretation.

The arts play an important role in science and engineering and hold the knowledge and skills a person needs to participate actively in civic life. The arts can provide ways for both scientists and engineers to broaden their understanding of concepts from diverse disciplines and generate creative, innovative solutions to unstructured problems. In particular, the arts can help people develop skills such as visual thinking; recognizing and forming patterns; modeling; getting a “feel” for systems; and the manipulative skills learned by using tools, pens, and brushes are all demonstrably valuable for developing STEM abilities (Root-Bernstein, [24]). The art provides students with problem-solving skills, innovative mindsets, communicative attitudes and motivation. There have been experimental studies which indicate that intense exposure to art develops superior spatial-visual coordination and other basic skills (Shuster, [25]).

Business leaders and economists emphasizing that both the arts and humanities provide the creative and critical thinking skills workers need in a new technology driven economy that emphasizes multidisciplinary pursuits such as biotechnology, nanotechnology, green energy, clean technologies, and digital media (Root-Bernstein, [243]).

3 Proposed Transdisciplinary Graduate Education

Trans-sector Innovation for Sustainable Development

The major factor of the *trans-sector* concept is that governments together with industries should develop

policies and strategies that will bring various sectors together to tackle and understand the current and future impact of key disruptions on employment levels, skill sets and recruitment patterns in different industrial sectors.

“Given the complexity of the change management needed, businesses will need to realize that collaboration on talent issues, rather than competition, is no longer a nice-to-have but rather a necessary strategy. Multi-sector partnerships and collaboration, when they leverage the expertise of each partner in a complementary manner, are indispensable components of implementing scalable solutions to jobs and skills challenges. There is thus a need for bolder leadership and strategic action within companies and within and across industries, including partnerships with public institutions and the education... These efforts will need to be complemented by policy reform on the part of governments.” (World Economic Forum, 2016 [26])

We propose a unique transdisciplinary Ph.D. program and curriculum representing eight main sector activities selected from primary, secondary and tertiary (service) sectors in the United States which impacts the global economy. Namely; healthcare, technology (information technology, nanotechnology, biotechnology, 3D printing, robotics, artificial intelligence etc.) finance & business, manufacturing, energy, transportation, defense and agriculture. There is an inter-relationship among the products provided by all these sectors. In other words, one sector’s products are interrelated with other sectors’ products. For example, efficiency of manufacturing products depends on many other sectors’ products. “A number of drivers of change will have severe impact within specific industries. For example, new energy supplies and technologies will have a particular impact on the Energy, Basic and Infrastructure and Mobility industries. Processing power and Big Data will have an especially strong impact on Information and Communication Technology, Financial Services and Professional Services (World Economic Forum, [26]). Naturally, these sectors should start working together towards a common integrated solution of the complex problems and issues facing mankind in the 21st century. The main challenge will be inte-

grating this whole concept into the transdisciplinary advanced education. Not only the physical integration of trans-knowledge into a transdisciplinary advanced education plays a role, but also the integration of different sectors that are not currently working together is challenging. The real question is then: how integration of complexity and effort can be minimized in building bridges between various sectors? This requires a greater focus on broad customary *digital education* (instructional practice that effectively uses technology to strengthen a student's learning experience) integrating A-STEM-H areas and the development of inherently transdisciplinary education processes and curriculum (Ertas, [27]).

Integration of functions especially that are syntactic in nature, provided by different sectors, is very slow and inefficient at this time – trans-sector *interoperability*: exchange of information of two or more sectors and use of the information that has been exchanged is problematic. Minimization of the integration complexity effort is the key issue for the success of trans-sector innovation. Semantic web service is one of the recent state-of-the-art developments which can be used in trans-sectors innovation for minimizing the integration effort (Bastiaansen and Baken,[28]).

The proposed program aims to provide a semantic problem solving platform (SPSP) that facilitates personalizable, transdisciplinary education where problem solving resources can be easily connected based on semantics in order to solve problems. The connection between students and resources can be made via [29]:

1. semantic interfaces, which interpret and understand problems;
2. semantic analysis, which analyzes the resources available; and
3. semantic synthesis, which integrates multiple resources into a solution.

Unification and integration of knowledge from sectors through transdisciplinary educational program is an ideal dream. Trans-sector knowledge and tools creation and integration into a transdisciplinary advanced education will be the main objective of this new program. Through this project we will bring up some promising trans-sector innovation ideas and provide new concepts for trans-sector innovation framework. Social, economic and environmental

dimensions of the transdisciplinary sustainable development will be augmented in the curriculum.

The idea of trans-sector innovation brings stakeholders together from academia, industry and government to solve complex problems by relying on merged perspectives. The major element of the trans-sector concept is that governments and industries need to develop policies and strategies that will bring diverse sectors together to tackle some of the complex and discouraging issues that exist in today's world. By bringing the diverse sectors together, common vexing problems will be solved as different participants react to different aspects of the problem in different ways, but all still with the same direction or goal in mind (Budde, [26]). This type of collaboration can spawn innovative solutions that could have impact on the solution of complex problems.

3.1 Proposed Transdisciplinary Ph.D. Curriculum

Students entering transdisciplinary Ph.D. program must have already earned a MS degree and will take following core, supplementary and complementary courses.

3.1.1 Transdisciplinary Core Courses

Educate the next generation with TD skills and create a world-class workforce.

There is a need for Transdisciplinary Design Culture (TD - DC) in higher education which can be built on the existing foundation that is provided by A-STEM-H. As shown in Figure 2, those four TD core courses should be in perfect harmony – they should be interconnected for the mutual exchange of knowledge. TD core courses are designed in a way that the specific subjects within and among the TD core courses can be easily synchronized and complement each other. Then, we can assume that interconnectivity exists and TD core courses are connected without boundaries within the TD–DC domain. This process provides a knowledge capability that is greater than the sum of the contributing core courses (Ertas et al. [1]).

The content of the four core TD courses will include information and knowledge common to multiple disciplines and also aforementioned eight main sector activities. The four synchronized TD core

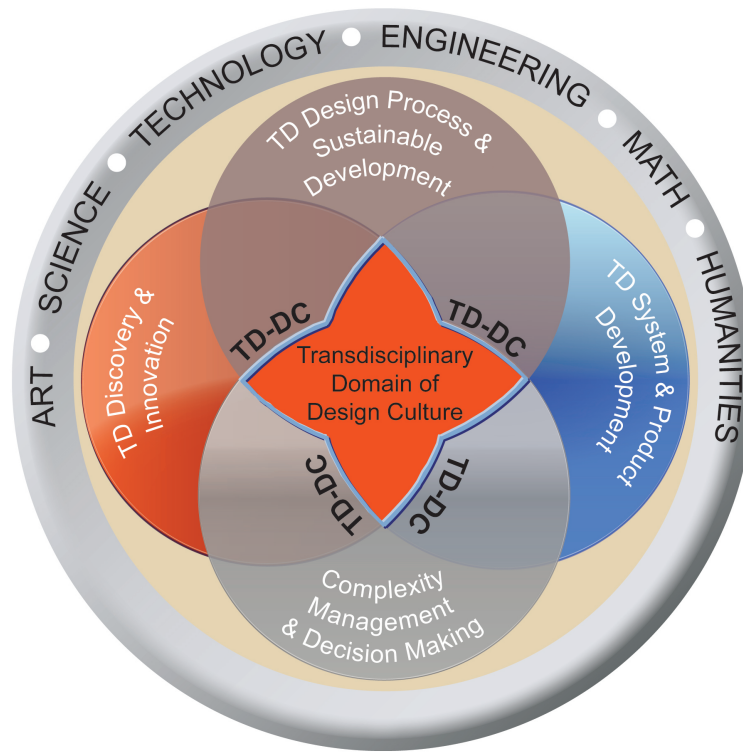


Figure 2: Domain of Transdisciplinary Design Culture (Ertas et. al. [1]).

courses will provide the students with a foundation in the TD skills required to identify, frame, and address important practical problems that cut across disciplinary boundaries. The proposed four TD core courses will support collaborative research based TD program which will be highly multidisciplinary and will represent A-STEM-H (see Figure 2). Contents of the four proposed TD core courses are:

1. Complexity Management & Decision Making:

A practical foundation for complexity management (related to human behavior, societal systems, economic systems, and environmental systems) will be presented that enables a system's complexity to be evaluated against its functions and qualitative factors, such as social mores and human values. The course will cover a) definitions and characteristics of complexity; b) understanding complexity: thought and behavior; c) modeling of complex systems; d) tools and methods for managing complex systems; e) strategies for reducing social complexity; f) complexity and structure; g) management of knowledge and integration; h) managing complexity through systems design; and i) Interactive Management (IM).

2. Transdisciplinary Design Process & Sustainable Development:

Fundamentals of TD design and research processes and applications, models to address trans-sector digital interoperability, TD assessment and methodology development to guide research, policy and action towards sustainability will be covered. Students will learn broad research skills and knowledge in strategies for sustainable integration, sustainable resource use and management, environmental conflict resolution, policy formulation and decision-making. Interoperability framework tool (ATHENA), Interpretive Structural Modeling (ISM) tool to decompose complexity due to integration will be introduced. Rural and urban sustainability, ecological sustainability, the interconnectivity of environment, economy and society will also be covered.

3. Transdisciplinary Discovery and Innovation:

The focus of this course is to enable the students to work jointly with others across disciplines. This course covers: generic design; idea generation and management; brain-writing pool and idea structuring; tradeoff analysis methodology (TAM); collaborative activities, practice

and research ethics; TD research process using a systems approach; impact of social issues on design; TD case studies; the role of experts in TD research processes; the use of Big Data to address world's most pressing societal, global, business, and educational complex issues will also be covered.

4. **Transdisciplinary System and Product Development:** This course teaches system and product development methods, techniques and tools so that students can have a big-picture view of the whole system/product lifecycle and can use systematic approaches to design and develop products and systems. Risk assessment, and how to deal with uncertainties will also be covered.

3.1.2 Supplementary Courses

1. **Biomimetic Systems 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 presented for engineers to access biological knowledge, identify relevant biological phenomena, comprehend material in the biological disciplines, and apply analogical reasoning to create new knowledge.

The objectives of this course are provide students with 1) an introduction to a broad range of biological systems; 2) a foundation in the application of analogical reasoning in transdisciplinary conceptual design of products, processes, and systems; 3) a generalized methodology for identifying and applying biological phenomena to engineering problems; and 4) an understanding of the application of computational tools (cyberinfrastructure) to search another discipline, locate phenomena, and identify relevance of phenomena.

2. **Uncertainty Analysis in System Design:** Uncertainty occurs in most engineering systems. Uncertainty may arise from variability inherent in systems and from incompleteness of statistical data. Techniques will be developed that can be used to quantify uncertainty and risk inher-

ent in engineering systems. These techniques will be applied to examples that include: mechanical engineering, bioengineering, electrical engineering, and computer engineering, etc.

3. **Technological Innovation, Entrepreneurship & Business:** Students will be prepared for managing innovation and entrepreneurship, how to use tools and techniques needed to manage and exploit technological investments and opportunities for technical innovations that can lead to viable commercial products and profitable businesses.
4. **Complex Problem Case Studies:** In this course, students will be allowed (a) to develop their own research-based, open-ended complex case studies related to uncertain events such as broad range of Global risks – when they occur, these events can cause significant negative impact on the state of the world. (b) Propose solutions, employing critical and creative thinking skills.

Some of the likelihood of Global risks are: health issues (e.g. rapid and massive spread of infectious diseases etc.), energy price shock to the global economy, unmanageable inflation, extreme weather events (e.g. floods, storms, etc.), failure of climate-change adaptation, major natural catastrophes (e.g. earthquake, tsunami, volcanic eruption, geomagnetic storms), food crises, water crises, large-scale cyber attacks, breakdown of critical information infrastructure and networks, massive and widespread misuse of technologies (e.g. 3D printing, artificial intelligence, geo-engineering, synthetic biology, etc.), climate change, environmental degradation, urbanization, rising income disparity, weakening of international governance [30]

Students will be working in research teams to give them the opportunity to develop and practice the collaborative, interpersonal and organizational skills that are crucial to strengthen the students' teamwork and leadership abilities.

3.1.3 Complementary Courses

Students are required to take one (1) complementary course chosen from any discipline – in art & science, humanities and engineering as part of their coursework.

4 Discussions

As shown in Figure 1, sub-domain of A-STEM-H created at the intersection of the two domains (art & science and technology & engineering) that have the greatest value to prepare students for effective transitions into technological innovation, entrepreneurship and business. Scientists and engineers play an important role in building the 21st century science and technology enterprises that will create solutions and jobs essential for solving large complex transdisciplinary problems faced by the society. Entrepreneurship using innovative business enterprises adds to the secure development of social, economic, and environmental concerns related to human quality of life.

Sub-domain created by technology-engineering-math adds value and knowledge for features technological invention and discovery – requires creativity and imagination. There is almost no creativity without imagination. Advances in the mathematical sciences creating new Technologies, discoveries and transforming industries.

“Imagination has brought mankind through the Dark Ages to its present state of civilization. Imagination led Columbus to discover America. Imagination led Franklin to discover electricity. Imagination has given us the steam engine, the telephone, the talking-machine and the automobile, for these things had to be dreamed of before they became realities. So I believe that dreams – day dreams, you know, with your eyes wide open and your brain-machinery whizzing – are likely to lead to the betterment of the world. The imaginative child will become the imaginative man or woman most apt to create, to invent, and therefore to foster civilization.” – L. Frank Baum [31].

Sub-domain of A-STEM-H created at the intersection of the two domains (Math and Humanities) is the central to the body of prescriptive knowledge about decision making – a sophisticated mathematical model of choice that lies at the foundation of most contemporary research methods and techniques. Problem solving and decision making is mainly concerned with how people reduce problems down to size – how they apply approximate, heuristic techniques to handle complexity that cannot be handled exactly.

The increasing understanding that managing with complexity is essential to human decision making and strongly influences the directions of research – a new body of mathematical theory developing around the topic of computational complexity is establishing a powerful new computational tool [32].

The last sub-domain is the creative thinking and scientific advancement. Science plays an important role for scientific advancement and creating innovative technologies. As technological innovation, globalization, and international competitiveness continue to challenge business organizations, creative thinking skills and the ability to solve vexing problems have become necessary for students.

A-STEM-H transdisciplinary domain teaches students new skills aimed at creativity, innovation, and working across knowledge fields; offers an approach that synthesizes methodologies from multiple fields; teaches the ability to collaborate across multiple spheres of knowledge and practice; prepares students to design, develop, and deliver a system that qualifies a student to be workforce ready.

Interpretive Structural Modeling (ISM), a methodology for dealing with complexity is used to decompose the complex interactions of trans-sectors (Ertas, et al., [33]). As shown in Figure 3, using expert opinions, Structural Self-Interaction Matrix (SSIM) of contextual relationship of eight trans-sectors was established. The following four symbols were used to describe the interactions between the trans-sectors in the SSIM.

- The letter V stands for events when the row element influences the column element.
- The letter A stands for events when the column element influences the row element.
- The letter X stands for events when the row and column elements influence each other.
- The letter O stands for events when there is no relationship between the row and column elements.

In developing structural self-Interaction matrix, if the relationship between factors is weak, it is assumed that there is no relationship between factors. Then the adjacency matrix, was developed by transforming SSIM into a binary matrix by substituting V, A, X, and O by 1 and 0 per the schema described above in the matrix that reflects the directed relationships between the elements (Ertas, et

	Energy 1	Healthcare 2	Technology 3	Agriculture 4	Manufacturing 5	Transportation 6	Finance & Business 7	Defense 8
Energy 1	\	V	X	X	V	V	O	V
Healthcare 2		\	A	A	A	O	O	O
Technology 3			\	V	V	V	A	V
Agriculture 4				\	A	A	A	O
Manufacturing 5					\	V	A	V
Transportation 6						\	A	V
Finance & Business 7							\	V
Defense 8								\

Figure 3: Structural self-interaction matrix (SSIM) for trans-sector activities.

	1	2	3	4	5	6	7	8	Driving power
Energy 1	1	1	1	1	1	1	0	1	7
Healthcare 2	0	1	0	0	0	0	0	0	1
Technology 3	1	1	1	1	1	1	0	1	7
Agriculture 4	1	1	1	1	1	1	0	1	7
Manufacturing 5	1	1	0	1	1	1	0	1	6
Transportation 6	1	1	0	1	0	1	0	1	5
Finance & Business 7	1	1	1	1	1	1	1	1	8
Defense 8	0	0	0	0	0	0	0	1	1
Dependence	6	7	4	6	5	6	1	7	Σ = 42

Figure 4: Final reachability matrix.

al., [33]). Then, final reachability matrix, R_f with transitivity which includes driving power and dependence of each trans-sector was obtained (see Figure 4). Summation of ones in the corresponding rows gives the driving power and the summation of ones in the corresponding columns gives the dependence. Level partitioning along with the final reachability matrix helps to build the diagraph (directed graphs) for trans-sector activities shown in Figure 5. This figure depicts visually the direct and indirect relationships between trans-sector activities and shows the five level decompositions of the complex inter-relationship.

Since large number of lines enter and leave sectors of energy (1), agriculture (4), transportation (6) and manufacturing (5) shown in Figure 5, they are the most critical and important sectors among others. These four sectors not only affect but also they are affected by the other sector activities – they are linkage sectors (see Figure 6). Thus, trans-sector knowledge and tools creation and integration into a transdisciplinary graduate education should be considered for comprehensive integrative curriculum design.

As shown in Figure 6, all eight trans-sector activities have been classified into four categories (MIC-

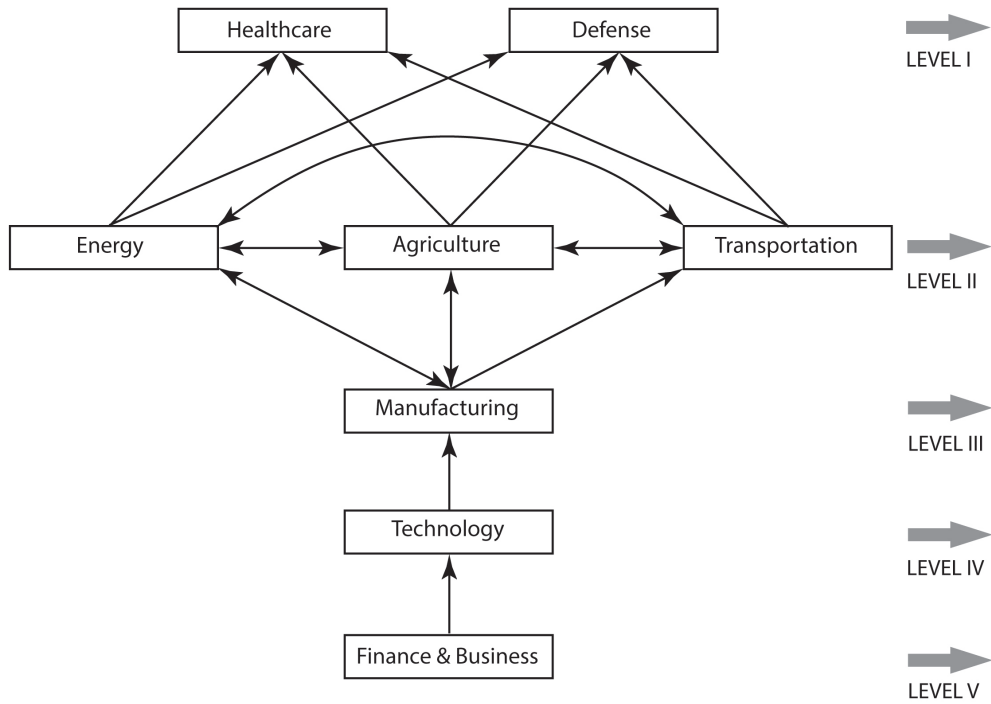


Figure 5: Directed graph for trans-sector activities.

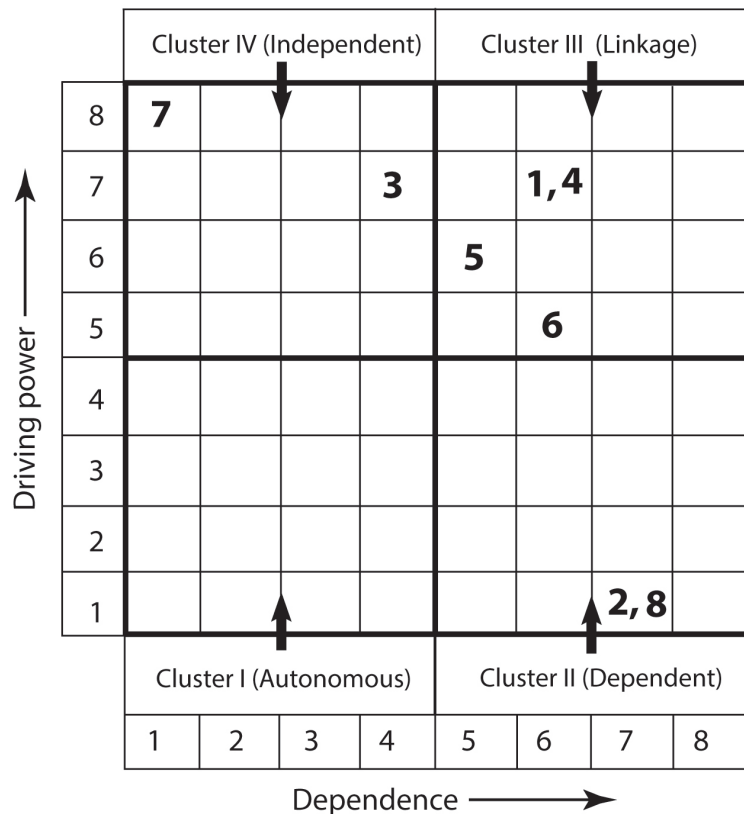


Figure 6: MICMAC Analysis for trans-sector activities.

MAC analysis). The purpose of MICMAC analysis is to arrange the factors with respect to their driving power and dependence in four clusters. Cluster I includes autonomous factors. As seen from the figure, they have low driving power and low dependence, hence they can be eliminated from consideration. For this case, no sector has been identified as an autonomous factor. This indicates that there is no disconnected sector in trans-sector activities.

Cluster II includes dependent sectors activities that have low driving power and high dependence. As seen from Figure 6, sectors healthcare (2) and defense (8) have a smaller guidance power but it is extremely dependent to the other sector activities and don't affect other sector activities. However, they are also very important sectors to be considered for the curriculum development as they are positioned at the top of the hierarchy (see Figure 5).

Cluster IV includes independent sectors of finance & business (7) and technology (3) with a strong drive power but very weak dependence. These two sectors are the key driver for the curriculum development as they impact on the other sectors activities but not necessarily affected by the other sector activities. Finance & business sector is the source sector since it has only outgoing path.

5 Conclusion

The Fourth Industrial Revolution, which includes developments in previously disjointed fields such as artificial intelligence and machine-learning, robotics, nanotechnology, 3-D printing, and genetics and biotechnology, will cause widespread disruption not only to business models but also to labour markets over the next five years, with enormous change predicted in the skill sets needed to thrive in the new landscape [26].

“The impact of technological, demographic and socio-economic disruptions on business models will be felt in transformations to the employment landscape and skills requirements, resulting in substantial challenges for recruiting, training and managing talent.” (World Economic Forum, 2016 [26])

During previous industrial revolutions, it often took decades to build the training systems and labour market institutions needed to develop major new

skill sets on a large scale. Given the upcoming pace and scale of disruption brought about by the Fourth Industrial Revolution, however, this is simply not be an option. Without targeted action today to manage the near-term transition and build a workforce with future proof skills, governments will have to cope with ever-growing unemployment and inequality, and businesses with a shrinking consumer base. Moreover, these efforts are necessary not just to mitigate the risks of the profound shifts underway but also to capitalize on the opportunities presented by the Fourth Industrial Revolution. The talent to manage, shape and lead the changes underway will be in short supply unless we take action today to develop it.

For a talent revolution to take place, governments and businesses will need to profoundly change their approach to education, skills and employment, and their approach to working with each other. Businesses will need to put talent development and future workforce strategy front and centre to their growth. Firms can no longer be passive consumers of ready-made human capital. They require a new mindset to meet their talent needs and to optimize social outcomes. Governments will need to re-consider fundamentally the education models of today. As the issue becomes more urgent, governments will need to show bolder leadership in putting through the curricula and labour market regulation changes that are already decades overdue in some economies.

In conclusion, this paper motivates the need for a new transdisciplinary graduate curriculum development. The author proposes trans-sector knowledge and tools creation and integration into a transdisciplinary graduate education. Trans-sector advocacy is important in the education sector helping to support the process of unifying common shared methods and tools used by major sectors impacting the global economy. Students educated through proposed transdisciplinary education will develop fast transition and adaptation time in different sectors mentioned in this paper.

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1.2

Table 1: Brokers by a Criterion that Standardized Brokerage Scores > 1.64 for the Washington University TREC site in 2011, 2013 and 2014

Brokerage Relations	Investigator Id		
	2011 (N=24)	2013 (N=31)	2014 (N=31)
1. Coordinator	17, 21, 23	1, 5, 6, 17, 21, 31	5, 17, 21, 31
2. Consultant	17, 21	17, 20, 21	17, 21, 28
3. Liaison	17, 21	17, 21	17, 21, 28
4. Representative/Gatekeeper	17, 21	1, 17, 21, 31	1, 17, 21, 31