Transdisciplinary Collaboration as a Vehicle for Collective Intelligence: A Case Study of Engineering Design Education

Article *in* International Journal of Engineering Education · January 2015

4 authors, including:

Atila Ertas
TTU
126 PUBLICATIONS **1,580** CITATIONS

SEE PROFILE

Pratap Chillakanti
Global Entrepreneurs Network Inc.
7 PUBLICATIONS **24** CITATIONS

SEE PROFILE

Turgut Baturalp
Texas Tech University
16 PUBLICATIONS **53** CITATIONS

SEE PROFILE

Transdisciplinary Collaboration as a Vehicle for Collective Intelligence: A Case Study of Engineering Design Education*

ATILA ERTAS, JASMIN ROHMAN, PRATAP CHILLAKANTI and T. BATUHAN BATURALP
Texas Tech University, Department of Mechanical Engineering, Lubbock, Texas 79409, USA.
E-mail: atila.ertas@ttu.edu

The main objective of this paper is to introduce a new transdisciplinary collaborative research process model to develop collective intelligence through input from research teams as well as academic and non-academic experts. The paper discusses the need for new types of collaboration to solve complex problems and reviews the development of transdisciplinary approaches and collective intelligence. The paper proposes a transdisciplinary collaborative research process composed of three parts: (1) team building and collaborative problem understanding; (2) development of collective intelligence through interpretive structural modeling to classify the problem factors according to driving power and dependence, and (3) use of design structure matrices for transdisciplinary assessment and knowledge integration to form project teams. The proposed process model is illustrated through an example of a rural eco-village system of systems (SoS) drawn from the context of a senior capstone design course.

Keywords: transdisciplinary collaboration; information sharing; collective intelligence; interactive management; interpretive structural modeling; design structure matrix; eco-village

1. Introduction

Over recent years, there has been increasing interest among researchers and educators for organized collaboration on the national and international levels. The evolution of large scale collaborative efforts between researchers from diverse disciplines was spawned from the necessity to increase efficiency in solving complex problems that require knowledge from multiple disciplines. Realizing the benefits from collaborative research, numerous initiatives have been launched to develop transdisciplinary research groups and establish new or larger centers of excellence [1–3].

One of the most constructive forms of knowledge transfer, for all partners involved, is Joint development of technologies, where companies and universities work together in pursuit of research objectives that are of mutual benefit, and are jointly managed under a collaborative agreement. In comparison with consultancy, contracts, or grants collaborative research is more interactive in nature and has the potential to beneficially persist for longer durations. Disciplines developed over the last few centuries are convenient for organizing information and for basic educational activities; however, approaching complex problems and developing complex social–technical systems to address such problems requires a transdisciplinary approach. Complex problems by definition do not observe disciplinary boundaries, and effective collaboration on any level requires facilitation via an organizational structure.

Because of the following reasons collaboration on research and educational activities are not only useful, but imperative [4]:

- Collaboration accelerates the pace of new discoveries and the expansion of human knowledge.
- Innovation of technologies occurs through global cross communication.
- Transdisciplinary collaboration in large-scale multi-national partnerships initiates speedy exploitation of promising results.
- Research partnerships are essential in solving complex problems and to optimize knowledge acquisition.
- Collaborative, transdisciplinary educational activities can better prepare today's students to solve the complex problems that face mankind.

Collaboration among people from different nations in research and education can substantially benefit all parties involved. In order to meet new challenges in the 21st century, universities around the world are seeking to broaden their engineering education systems. In the near future, engineering education will be an international enterprise. Hence, institutions of different nations must work together.

The world is constantly growing smaller and smaller. Challenging technical, medical, social, and cultural issues are no longer just local concerns—issues and problems must more and more be considered from a global perspective. Communication, collaboration, and education on a global scale are the keys to solving the complex problems

and issues facing mankind in the 21st century. The successful development of a network of global collaboration would provide a common sharing of knowledge and benefit everyone by greatly increasing the ability to solve complex problems facing the peoples of the world. Such problems include living conditions, environmental issues, health and medical issues, energy issues, transportation issues, communication issues, and educational issues [4].

Although collaboration is not a new idea, new opportunities for collaboration exist in the 21st century's global body of knowledge and information-driven economy. Technology has reduced distances in time and space while enhancing communication, hence opening the possibilities of exploring new boundaries in the area of international Transdisciplinary (TD) collaboration. Such international collaboration requires not only active participation of faculty but also participation of the top administrators of educational institutions. Faculty and administrators should find innovative ways to work together across international boundaries. Recent advances in information and communications technologies are providing new opportunities for international cooperation in education and research [4, 5].

2. Transdiscipline

An interdisciplinary methodology has been defined as "two or more disciplines which combine their expertise to jointly address an area of common concern" (Davies & Devlin [6]). Ertas, et al., [7] indicated that interdisciplinarity forces one to "think across, beyond, and through the academic disciplines to encompass all types of knowledge about an idea, issue, or subject."

The creative potential of cross-disciplinary research increases as one move from interdisciplinary to transdisciplinary approaches [8]. The criteria of novelty and importance appear to differentiate transdisciplinarity from interdisciplinarity, which is the integration of insights from multiple disciplines. Intelligence and creativity provides a connection to transdisciplinarity [9].

Many scientists and engineers made excellent contributions to the development of a transdisciplinary methodology since 1970s [10–14]. Klein states that the term transdisciplinarity signifies a new structure of unity informed by the world view of complexity in science, a new mode of knowledge production that draws on expertise from a wider range of organizations, and collaborative partnerships [15]. Hadorn, H. G. et al., underline that transdisciplinary research transgresses boundaries between scientific disciplines and between science and other societal fields and includes deliberation about facts, practices and values [16]. There is a need for transdisciplinary research when knowledge about a societally related problems are 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 [17].

"Transdisciplinarity is a practice of acquiring new knowledge through education, research, design, and production with a broad emphasis on complex problem solving. The goal of transdisciplinary practice is to improve our understanding of complex issues by extracting the valuable aspects of typical academic disciplines and thereby generate
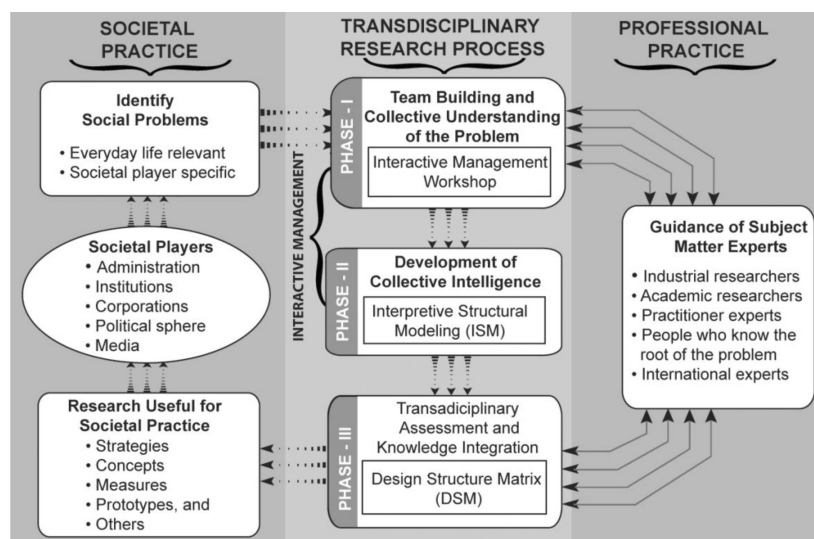

Fig. 1. TD research process model.

both a more integrative and universal solution to support an issue of importance to society" [18].

3. Transdisciplinary collective intelligence

Transdisciplinary collaboration is essential to solve society's "messy" or "wicked" problems, e.g., those with inter-connected influences and requirements such that the proposed solution causes other problems, i.e., climate change; response to natural disasters; enhanced national security [19]. Transdisciplinary collaboration has a big potential to speed the rate at which research can contribute to the understanding of the problem, accelerate the pace of new discoveries, and expand human knowledge. Transdisciplinarity provides a good framework and add to the current approaches for collective intelligence. Transdisciplinary collective intelligence is a new mode of information gathering, knowledge creation, and decision-making that draws on expertise from a wider range of organizations (academic or non-academic) and collaborative partnerships.

Fig. 1 shows the proposed TD research process model which is conceptualized in three phases: 1) collaboratively defining the research problem objective(s) and building a collaborative research team; 2) developing collective intelligence to solve complex problems in question; and 3) TD assessment and knowledge integration.

3.1 Team building and collective understanding of the research problem

TD-teams can be developed with distributed leadership—team leadership can change in accordance with the particular expertise required. Most of the time, structuring and understanding of a complex problem may become problematic—collaborating team members may not even agree on what the problem is and no solution can make everyone happy [20]. Considering a hypothetical example, imagine students in a senior design class working on a research project for a class. A sample research project might be to design and develop ideal self-sustaining rural eco-village systems of system (SoS) (approximately 100 people live in independent 25 homes).

3.1.1 Interactive management (IM) workshop

Assume that research sub-project teams of four with specific roles for each sub-project teams are considered. Depending on the assigned task, each sub-project team may have minimum of three and maximum of five students. Using any communication platform, a workshop can be organized where sub-project teams will introduce their project proposals (concepts) about the project being explored.

Through dialog, the collective best ideas of sub-project teams will emerge and the incorrect or fuzzy ideas that teams held at the outset will be recognized as incorrect or sharpened to make them useful. Through the Interactive Management (IM) process [21], ideas with high interaction will be grouped into clusters. Thus, team members can identify and examine cluster interactions internally and interactions between clusters. Clusters will be placed in a sequence by using Interpretive Structural Modeling (ISM) [19]. It is important to note that the workshop coordinator should help the team members to understand the importance of team transactive memory process (team members in a group develop a shared system for encoding, storing, and retrieving information where each person is responsible for memorizing only part of the total information) [22]. Through Interactive Management (IM) Workshop sub-project team members will experience the mutual understanding and learning that are an integral part of the TD research process.

3.2 Development of collective intelligence—interpretive structural modeling

Interpretive Structural Modeling (ISM), a methodology for dealing with complex issues was proposed by Warfield in 1973. It is a computer-assisted learning process that provides fundamental understanding of how various parameters (elements, variables, system components, etc.) relevant to the problem or issue interrelated and thus helps researchers to structure them in a meaningful manner to develop collective intelligence to overcome challenging complex problems.

This interactive learning, information processing, and developing collective intelligence is especially useful for working in a group to develop a map of the complex relationships between various elements involved in a challenging complex issue. The relationship map includes paths of ideas and threads of thought to transform unclear and poorly expressed mental model of an issue into a visible, well defined, and relatively easily solvable model. The fundamental approach of this process is to use academic and non-academic experts' practical experience and knowledge to decompose a complex issue into smaller sub-issues and build a simpler multilevel structural model. For the hypothetical example, general activities to build an Interpretive Structural Modeling are shown in Fig. 2. Note that the sequence of these activities may change from one application to another.

3.2.1 Sequence of activities to develop ISM model

The first step in ISM process is to organize a group of people with relevant knowledge, skills, and background. This group of team should consist of
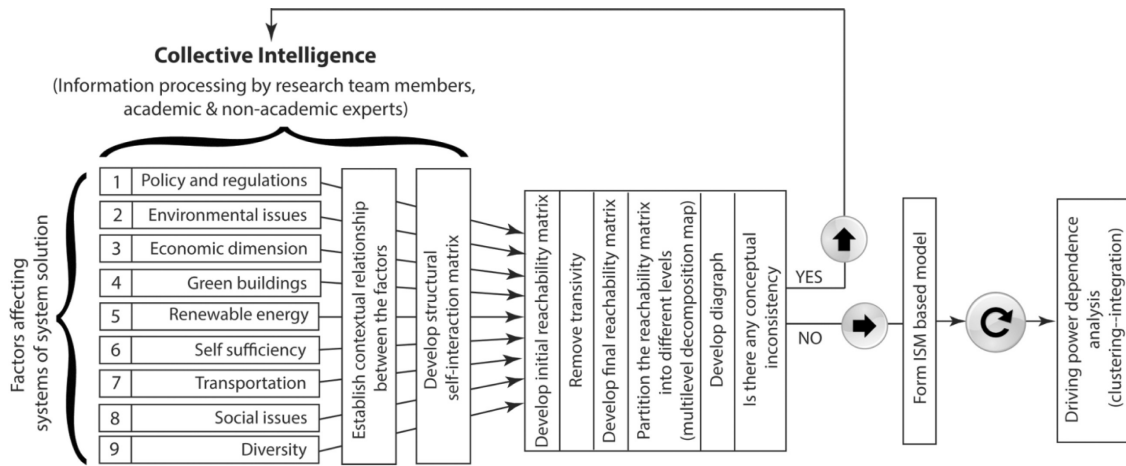
Fig. 2. Sequence of activities to develop interpretive structural model.

academic and non-academic experts from diverse disciplines (Fig. 1). A coordinator who will control the ISM process should not only be knowledgeable in the subject matter but also be familiar with the ISM process. At this stage, it is also important clearly identify the problem (issue) which will be studied as explained in section 3.1.1.

Second step is identify and define the factors effecting issue as shown in Fig. 2. Through brainstorming and consultation with the domain experts, research group members work together to document all the possible factors (elements) whose relationships are to be modeled. Then the most important factors will be identified for the model development. Nominal Group Technique (NGT) is an efficient method for generating ideas for defining a set of factors [23]. Five basic steps of NGT process are given as: (a) clarification of a trigger question, (b) silent generation of ideas in writing by each group members, (c) round-robin recording of the ideas, (d) ongoing discussion of each idea for clarification and editing, and, (e) voting to obtain a preliminary ranking of the ideas in terms of significance.

Structural self-interaction matrix
The following step is to establish contextual relationship to develop structural self-interaction matrix (SSIM) shown in Fig. 3. Using expert opinions along with research team members SSIM is develop which shows the direction of contextual relationship among the factors effecting the issue or problem. Four symbols are used in this matrix are:

- Enter **V** when the relation is from i to j (in the reachability matrix substitute in the (i,j) entry as 1 and (j,i) entry as 0).
- Enter **A** when the relation is from j to i (in the reachability matrix substitute in the (i,j) entry as 0 and (j,i) entry as 1).

- Enter **X** when the relation is from I to j and j to I, both direction (in the reachability matrix substitute in the (i,j) entry as 1 and (j,i) entry as 1).
- Enter **O** when there is no relationship between the row (i) element and the column (j) element (in the reachability matrix substitute in the (i,j) entry as 0 and (j,i) entry as 0).

In developing structural self-Interaction matrix, if the relationship between factors is week, it is assumed that there is no relationship between factors.

Adjacency matrix
Then the adjacency matrix, R_a shown in Fig. 4 is 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

Fig. 3. Structural self-interaction matrix (SSIM) for relationship between factors.

$$R_i = \begin{array}{c} \text{Policy and regulations} \\ \text{Environmental issues} \\ \text{Economic dimension} \\ \text{Green buildings} \\ \text{Renewable energy} \\ \text{Self sufficiency} \\ \text{Transportation} \\ \text{Social issues} \\ \text{Diversity} \end{array} \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \end{array}$$

	1	2	3	4	5	6	7	8	9
1	1	1	0	1	1	0	1	1	0
2	1	1	1	1	1	0	0	1	0
3	0	0	1	0	0	0	1	0	0
4	0	1	1	1	0	0	0	1	0
5	0	1	1	1	1	1	0	1	0
6	0	0	1	0	0	1	0	1	0
7	0	1	0	0	0	0	1	1	0
8	1	0	1	0	0	1	0	1	0
9	0	1	1	0	0	1	0	1	1

Fig. 4. Adjacency matrix for directed relationships between the elements.

	1	2	3	4	5	6	7	8	9
Policy and regulations 1	1	1	1	1	1	1	1	1	0
Environmental issues 2	1	1	1	1	1	1	1	1	0
Economic dimension 3	0	1	1	0	0	0	1	1	0
Green buildings 4	1	1	1	1	1	1	1	1	0
Renewable energy 5	1	1	1	1	1	1	1	1	0
Self sufficiency 6	1	0	1	0	0	1	1	1	0
Transportation 7	1	1	1	1	1	1	1	1	0
Social issues 8	1	1	1	1	1	1	1	1	0
Diversity 9	1	1	1	1	1	1	1	1	1

$R_t =$

Fig. 5. Reachability matrix for directed relationships between the elements with transivity.

reflects the directed relationships between the elements. This matrix answers the question of "yes" or "no". In other words, starting from factor (i), can factor (i) reach to factor (j) to contribute and improve? If so, substitute in the (j) entry as 1 and (i) entry as 0). This means that there is a walk from (i) to (j). Main diagonal of reachability matrix is filled with ones.

Reachability matrix with transivity
The reachability matrix with transivity R_t is shown in Fig. 5. This matrix is checked for the transivity rule and will be updated until transivity is established. Transivity rule states that, if a factor (element) A is related to factor B and if factor B is related to factor C, then factor A is related to factor

C. Following transivity rule a reachability matrix which considers transivity is developed.

Final reachability matrix
Driving power and dependence of factors are also computed in the final reachability matrix as shown in Fig. 6. Summation of ones in the corresponding rows gives the driving power and the summation of ones in the corresponding columns gives the dependence.

Level partition
For level partition, the final reachability matrix, R_f along with antecedents of each element of prospects are used [24]. Previously obtained driving force and dependence helps to classify the factors into groups. These groups' positions are determined by the separation of antecedent set and reachability set. From these two sets intersection set is determined. The factors are common in the reachability set and antecedent set are included in the intersection set. These three sets help to identify the level of the factors. If all the factors of the intersection and reachability sets of any particular factor are the same, then that factor is identified as the top level group (level I group) in the *ISM hierarchy*. Once the top level factors are identified, it is removed from the set to identify the next level. This iteration process is repeated until all the levels are identified. As shown in Table 1, factors 3, 8, and 9 are found to be at level I. Hence, it will be positioned at the top level group in the *ISM hierarchy*. This process is repeated until all the levels are determined. The factors along with their reachability set, antecedent set, intersection set and levels, are shown in Tables 1, 2, 3, and 4. These levels help to build the diagraph and ISM model.

Formation of digraph and ISM based models
As shown in Fig. 7, the association of sets and binary relations through matrices can now be converted into graphical form by using theory of digraphs (directed graphs) [25]. If there is a relation-

	1	2	3	4	5	6	7	8	9	Driving power
Policy and regulations 1	1	1	1	1	1	1	1	1	0	8
Environmental issues 2	1	1	1	1	1	1	1	1	0	8
Economic dimension 3	0	1	1	0	0	0	1	1	0	4
Green buildings 4	1	1	1	1	1	1	1	1	0	8
Renewable energy 5	1	1	1	1	1	1	1	1	0	8
Self sufficiency 6	1	0	1	0	0	1	1	1	0	5
Transportation 7	1	1	1	1	1	1	1	1	0	8
Social issues 8	1	1	1	1	1	1	1	1	0	8
Diversity 9	1	1	1	1	1	1	1	1	1	9
Dependence	8	8	9	7	7	8	9	9	1	$\Sigma = 66$

$R_f =$

Fig. 6. Final reachability matrix for driving power and dependence of factors.

Table 1. Variables at level I (first iteration)

Variable	Reachability Set	Antecedent Set	Intersection Set	Level
1	1 2 3 4 5 6 7 8	1 2 4 5 6 7 8 9	1 2 4 5 6 7 8	
2	1 2 3 4 5 6 7 8	1 2 3 4 5 7 8 9	1 2 3 4 5 7 8	
3	2 3 7 8	1 2 3 4 5 6 7 8 9	2 3 7 8	I
4	1 2 3 4 5 6 7 8	1 2 4 5 7 8 9	1 2 4 5 7 8	
5	1 2 3 4 5 6 7 8	1 2 4 5 7 8 9	1 2 4 5 7 8	
6	1 3 6 7 8	1 2 4 5 6 7 8 9	1 6 7 8	
7	1 2 3 4 5 6 7 8	1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8	I
8	1 2 3 4 5 6 7 8	1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8	I
9	1 2 3 4 5 6 7 8 9	9	9	

Table 2. Variables at level II (second iteration)

Variable	Reachability Set	Antecedent Set	Intersection Set	Level
1	1 2 4 5 6	1 2 4 5 6 9	1 2 4 5 6	II
2	1 2 4 5 6	1 2 4 5 9	1 2 4 5	
4	1 2 4 5 6	1 2 4 5 9	1 2 4 5	
5	1 2 4 5 6	1 2 4 5 9	1 2 4 5	
6	1 6	1 2 4 5 6 9	1 6	II
9	1 2 4 5 6 9	9	9	

Table 3. Variables at level III (third iteration)

Variable	Reachability Set	Antecedent Set	Intersection Set	Level
2	2 4 5	2 4 5 9	2 4 5	III
4	2 4 5	2 4 5 9	2 4 5	III
5	2 4 5	2 4 5 9	2 4 5	III
9	2 4 5 9	9	9	

Table 4. Variables at level IV (fourth iteration)

Variable	Reachability Set	Antecedent Set	Intersection Set	Level
9	9	9	9	IV

ship between factors j and i, connection between factors will go from i to j. Finally, digraph is converted to ISM to see a broad representation of the interrelationship between the factors (Fig. 8).

MICMAC analysis—classification of performance measures

Performance goals for the eco-village may include: reduction of energy (using green buildings, wind and solar energy), water, land, and natural resource management, reduction of water use, waste treatment, recycling, roof-top capture of rainwater for landscape irrigation and production of fruits and vegetables guided by intertwined educational, economical, environmental, sustainable and social goals. MICMAC was developed by Duperrin and Godet in 1973 to study the diffusion of impact through reaction paths and loops for developing hierarchies for members of an element set [26]. The purpose of MICMAC analysis is to arrange the factors with respect to their driving power and dependence in four clusters [27]: (1) autonomous, (2) dependent, (3) linkage, and (4) independent factors. The driving power and dependence of

each of factors are imported from Fig. 6. Fig. 9 shows the driving power-dependence diagram for self-sustaining rural eco-village SoS.

3.3 TD assessment and knowledge integration

Transdisciplinary assessment (TA) includes integrating people (social), artefacts (technical), and
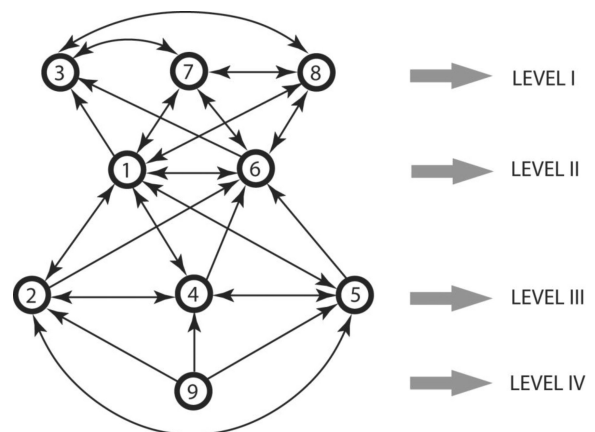
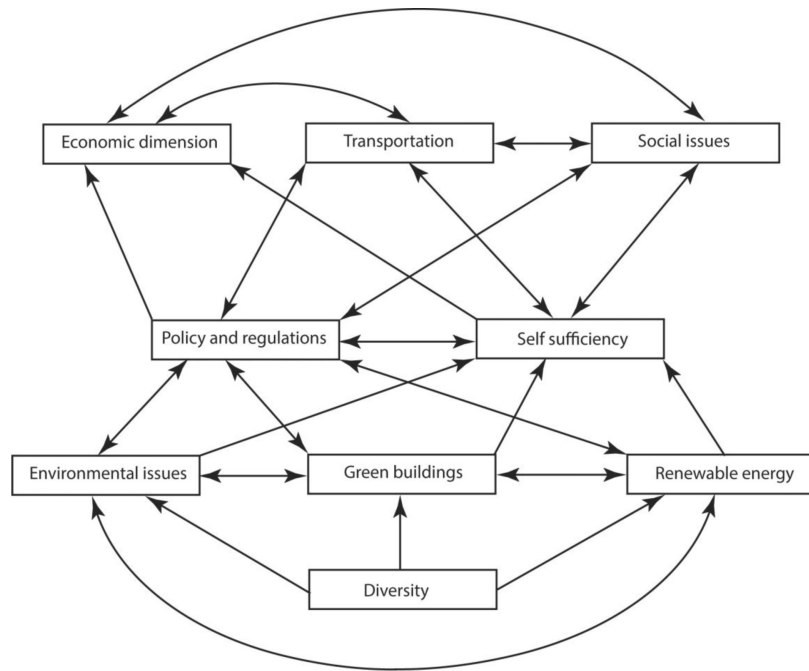**Fig. 7.** Digraph based on reachability matrix with relation strength.

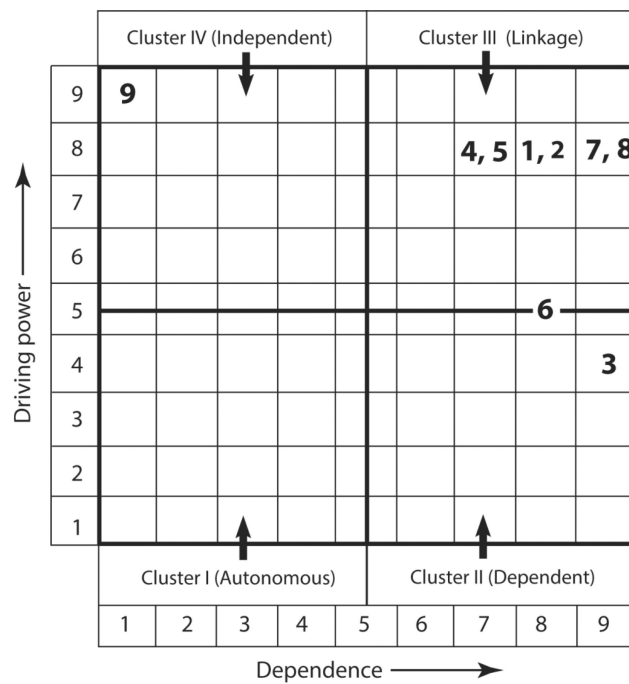**Fig. 8.** ISM based model for interrelationship between the factors.

Fig. 9. Driving power-dependence map for self-sustaining rural eco-village SoS.

knowledge (cognitive) associated with different scientific and non-scientific knowledge domains [28] into an appropriate methodology [29]. Societal players who are affected by a problem along with the research team must be drawn into the research process to effect scientifically valid research (Fig. 1).

In the third phase of TD research process, design structure matrix (DSM) is used for SoS design and development. DSM provides a simple, visible, well defined representation of complex systems that aids meaningful solutions to decomposition and integration problems [30, 31]. In order to reduce the technical complexity of eco village SoS research project, work will be distributed among several design and development student teams. The following steps are used to reorganize student research teams:

1. Decompose the research team into sub-project teams with specific functions, roles, or assignments—map the sub-project teams to product components.
2. Document the interactions between the teams.
3. Analyze potential reintegration of the teams via clustering (integration analysis)

Decomposition of research team into sub-project teams creates a crucial managerial challenge due to the complex web of interactions between teams and team members for design and development of eco village SoS. This effort can be coordinated and orchestrated by the system team. The system team manages the whole design and development process, interacts with all the sub-project teams, and provides guidance and ensures that the systems' compatibility with each other within the system of systems exists [32].

Complex systems such as SoS in this case, require communications and exchange of information among team members and teams. Information flow between team members can be created using a team-based DSM in order to better map teams, to address the SoS problems. Clustering (integration) of teams can provide new understandings into system decomposition and integration. To optimize the team collaboration for collective intelligent (knowledge integration through transactive memory process), interactions between teams within DSM clusters should be maximized and interactions between DSM clusters should be minimized [33]. While minimizing the size of the clusters some overlapping between the clusters is also recommended [34].

4. Discussions

The hypothetical example of an ideal self-sustaining rural eco-village systems of system (SoS) in a multi-project environment given in this paper can be created by optimizing natural resources—using renewable energy, growing much food as possible through intensive agriculture, community building, sharing common resources, and finally "all for one and one for all".

Factors in designing and developing an ideal self-sustaining rural eco-village SoS shown in Fig. 2 is simplified by lumping similar factors serving to same purposes. Such as renewable energy may include solar, wind, hydro energies. Environmental issues may include recycling, air, water, and soil protection. Self-sufficiency may include recycling, and sharing common resources (food production etc.), Diversity may include age, income levels, culture, color, being from different country, and social issues may include encouraging unity through diversity, fostering cultural expression, emphasizing holistic health practices, being committed to living in a community. Designing and developing an ideal SoS is not an easy task. Many subsystems (e.g., energy, green building, transportation, recycling, etc.) must be integrated to achieve an overall optimum SoS solution.

The main objective of this paper is to introduce a new TD research proses model in education which deals with such complex system development by creating and using collective intelligence through transdisciplinary collaborative effort. Interpretive Structural Modeling (ISM), a methodology for dealing with complex SoS design and development is the key component of this research. Building collective intelligence to understand how factors affecting SoS performance and their relationships are an important part of interpretive structural modeling.

After removing the transivities based on the reachability matrix as described in the ISM approach, the digraph (Fig. 7) is converted into the ISM and finally the structural hierarchy of the performance measure factors of SoS is developed as shown in Fig. 8. This figure depicts visually the direct and indirect relationships between the factors affecting the performance of ideal self-sustaining rural eco-village systems of system.

Two main important factors, self-sufficiency (measure 6) and policy and regulations (measure 1) shown in Figs. 7 and 8 are the most preliminary factors which need to be analyzed before other factors as most of the other factors depend on them. These two factors not only affect but also they are affected by the other factors. For self-sufficient eco village, the main goal must be a very high level of self-sufficiency and a very small ecological footprint. However, in some areas, laws and regulations can be major barriers for rural eco village development.

As shown in Figs. 7 and 8, factors economic dimension (measure 3), transportation (measure 7), and social issues (measure 8) are positioned at the top of the hierarchy. They are also very significant measures for the development of a rural eco village. Of course, one of the main reasons behind creating eco villages is families (social), rural eco village must have connection to the other world (transportation), and a true economy that is resulting from the value of people and benefited by balanced use of land (economic dimension). These three factors are strongly interrelated—affecting and affected from each other. These higher level factors have greater influence on the eco village SoS. Hence, when designing and developing such SoS, these three factors can be first evaluated and kept constant as much as possible during the perfor-

mance improvement. In other words, first make sure that transportation issues are solved, within certain limitations economic modeling is developed, and social issues are resolved, and then start iteration by changing the other remaining factors to find the best possible solution for the ideal self-sufficient eco village systems of system.

As shown in Fig. 9, all performance measures of factors effecting SoS have been classified into four categories. Cluster I includes autonomous factors. As seen in Fig. 9, they have low driving power and low dependence, hence they can be eliminated from the SoS. For this case, no factor has been identified as an autonomous factor. This indicates that there is no disconnected factor from the SoS.

Cluster II includes dependent factors that have low driving power and high dependence. As seen in Fig. 9, only economic dimension (measure 3) has a smaller guidance power but it is extremely dependent to the SoS— this factor may not affect other factors but it is affected by other factors of SoS.

The factors in the linkage cluster have to be given extreme importance due to their high driving power and high dependence power. Cluster III includes linkage factors of policy and regulations (measure 1), environmental issues (measure 2), green buildings (measure 4), renewable energy (measure 5), self-sufficiency (measure 6), transportation (measure 7), and social issues (measure 8). As being the most important factors, they affect and depend on other factors in SoS. Any action on any of the factor in cluster III will affect the entire SoS. Therefore, as mentioned earlier, designing such systems of system is a challenging task and seven major factors within this cluster which influence the SoS performance must be carefully analyzed and integrated with the whole projected system. Note that, self-sufficiency is on the border of the dependent and linkage cluster. This factor, not only can be affected by other factors of SoS but also it can affect the other factors.

Cluster IV includes independent factor of diversity (measure 9) with a strong drive power but very week dependence. This factor is the key driver for the eco-village SoS performance. Diversity is the strength and an important element. As diversity has impact on many factors, eco-village participants have to pay maximum attention to establish a diverse but integrated community for peaceful, healthy, and sustainable life so that issues will not be out of control.

5. Conclusions

In this paper, the author introduces a new transdisciplinary collaborative research process model in education for the purpose of developing collective intelligence through input from research teams, academic, and non-academic experts. The paper motivates the need for new types of collaboration to solve complex problems and discusses the development of transdisciplinary approaches and models of collective intelligence. The author proposes a transdisciplinary collaborative research process composed of three parts. First, team building and collaboration are used for problem understanding; Second, Collective intelligence is developed through structural modeling to classify problem factors according to driving power and dependence.

Eco-community determines the course of human interaction, the prospects for the impact on the natural environment, social issues, and sustainable peaceful, healthy life. Diverse participants in an eco-village may have their personal and collective choices and may have an enormous impact on their interaction in cooperative and competitive modes.

Developing self-sufficient eco village SoS in this paper is a hypothetical case study. Moreover, information processing to develop structural self-interaction matrix shown in Fig. 3 was based on few experts' opinions. The results of model analysis may differ in real world setting. Of course, capability of a group of team members along with academic and non-academic experts collectively can envision a better and different solution model for challenging complex problem such as this one.

It is important to note that ISM is a tool to identify the order and directions of the complexity of relationships among the system factors (elements). It does not provide any relative weight associated with the factors.

References

1. NIMHD Transdisciplinary Collaborative Centers for Health Disparities Research (U54), http://www.grants.gov/search/search.do?mode=VIEW&oppId=182155, Accessed 10 August 2013.
2. Transdisciplinary Research Recovery Centers for Community Health, http://www.nimhd.nih.gov/recovery/goRecoveryCenter.asp, Accessed 17 September 2013.
3. Grants Available for Transdisciplinary Research on Fatigue and Fatigability in Aging (NIH), http://www.humankinetics.com/aaccgrants/aacc-grants/grants-available-for-transdisciplinary research-on-fatigue-and-fatigability-in-aging, Accessed 17 September 2013.
4. A. Ertas, S. Gatchel, V. Rainey and M. M. Tanik, A Network Approach to Transdisciplinary Research and Education, *TheATLAS Publication*, **3**(2), 2007, pp. 4–12.
5. H. Zhang, T. Yang and M. C. Wu, Surgical clinical trials— need for international collaboration, *The Lancet*, **382**(9908), 2013, pp. 1876.
6. M. Davies and M. Devlin, *Interdisciplinary Higher Education: Implications for Teaching and Learning,* Centre for the Study of Higher Education, The University of Melbourne, 2007, Retrieved from http://www.cshe.unimelb.edu.au/pdfs/InterdisciplinaryHEd.pdf.
7. A. Ertas, T. Maxwell, V. P. Rainey and M. M. Tanik, Transformation of Higher Education: The Transdisciplinary

Approach in Engineering, *IEEE Transactions on Education*, **46**(2), 2003, pp. 289–295.

8. P. L. Rosenfield, The Potential of Transdisciplinary Research for Sustaining Linkages Between the Health and Social Sciences, *Social Science and Medicine*, **35**(11), 1992, pp. 1343–1347.

9. R. Weber, An Evaluating and Developing Theories in the Information Systems Discipline, *Journal of the Association for Information Systems*, **13**(1), 2012, Article 2.

10. B. Nicolescu, Methodology of Transdisciplinarity-Levels of Reality, Logic of the Included Middle and Complexity, Transdisciplinary, *Journal of Engineering & Science*, **1**(1), 2010, pp. 17–32.

11. C. Pohl, From Transdisciplinarity to Transdisciplinary Research, *Journal of Engineering & Science*, **1**(1), 2010, pp. 65–73.

12. A. Ertas, T. Kollman and E. Gumus, Transdisciplinary Educational Performance Evaluation through Survey, *The International Journal of Engineering Education*, **27**(5), 2011, pp. 1094–1106.

13. H. Eunsook, Engineering Transdisciplinarity in University Academic Affairs: Challenges, Dilemmas, and Progress, *Transdisciplinary Journal of Engineering & Science*, **3**(1), 2012, pp. 58–68.

14. D. Tate, T. Maxwell, A. Ertas, H. C. Zhang, U. P. Flueckiger, W. Lawson, A. D. Fontent and J. Chandler, Transdisciplinary Approaches for Teaching and Assessing Sustainable Design, *International Journal of Engineering Education*, **26**(2), 2010, pp. 418–428.

15. J. T. Klein, Disciplinary Origins and Differences, *In Australian Academy of Science Fenner Conference on the Environment: Understanding the population-environment debate: Bridging disciplinary divides*, Canberra ACT, 2004, 2004, pp. 10.

16. H. G. Hadorn, S. Biber-Klemm, W. Grossenbacher-Mansuy, G. H. Hadorn , D. Joye , C. Pohl , U. Wiesmann and E. Zemp, Enhancing Transdisciplinary Research: A Synthesis in Fifteen Propositions, *Handbook of Transdisciplinary Research*, Springer Science & Business Media, Chapter 29, 2007, p. 435.

17. K. Cronin, Transdisciplinary Research (TDR) and Sustainability. Environmental Science and Research (ESR) Ltd, http://learningforsustainability.net/pubs/TransdisciplinaryResearchandSustainability.pdf, Accessed 12 August 2012.

18. A. Ertas, K. M. Frias, D. Tate and S. M. Back, Shifting Engineering Education from Disciplinary to Transdisciplinary Practice, *International Journal of Engineering Education*, **31**(1A), 2015, pp. 94–105.

19. H. W. J. Rittel and M. M. Webber, Dilemmas in a General Theory of Planning, *Policy Sciences,* **4**, 1973, pp. 155–169.

20. P. J. Denning, Mastering the Mess, *Communications of the ACM*, **50**(4), 2007, pp. 21–25.

21. J. N. Warfield and A. R. Cardenas, *A Handbook of Interactive Management*, Iowa State University Press/AMES, Iowa, 1994.

22. D. M. Wegner, in B. Mullen and G. R. Goethals (eds), *Transactive Memory: A Contemporary Analysis of the Group Mind, Theories of group behavior*, Springer-Verlag, New York, 1986, pp. 185–208.

23. A. L. Delbecq and A. H. VandeVen, A Group Process Model for Problem Identification and Program Planning, *Journal of Applied Behavioral Science VII*, 1973, pp. 466 –91.

24. J. N. Warfield, Developing Interconnected Matrices in Structural Modeling, *IEEE Transactions on Systems, Man and Cybernetic*, **4**(1), 1974, pp. 51–58.

25. F. Harary, R. V. Norman and D. Cartwright, *Structural Models: An Introduction to the Theory of Directed Graphs*, Willey, New York, 1965.

26. J. C. Duperrin and M. Godet, Methode De Hierar Chization des Elements D'um System, *Rapport Economique de CEA*, 1973, pp.45–51.

27. A. Mandal and S. G. Deshmukh, Vendor Selection Using Interpretive Structural Modelling (ISM), *International Journal of Operations & Production Management*, **14**(6), 1994, pp. 52–59.

28. E. Becker, T. Jahn, E. Schramm, D. Hummel and I. Stieß, Sozial- okologische Forschung, Rahmenkonzept fur einen neuen Forderschwerpunkt, *ISOE Institut fur sozial- okologische Forschung*, **6**, 2000.

29. J. Hinkel, *Transdisciplinary Knowledge Integration: Cases from Integrated Assessment and Vulnerability Assessment*, Wageningen University Ph.D. thesis, Wageningen The Netherlands, 2008.

30. C. Alexander, *Notes on the Synthesis of Form*, Harvard University Press, Cambridge, 1964.

31. R. B. Tyson, Applying the Design Structure Matrix to System Decomposition and Integration Problems: A Review and New Directions, *IEEE Transactions on Engineering Management*, **48**(3), 2001, pp. 292–306.

32. A. Yassine and B. Dan, Complex Concurrent Engineering and the Design Structure Matrix Method, *Concurrent Engineering: Research and Applications*, **11**(3), 2003, pp. 165–176.

33. E. Rechtin, *Systems Architecting: Creating & Building Complex Systems*, Prentice-Hall, Englewood Cliffs NJ, 1991.

34. S. S. Altus, I. M. Kroo and P. J. Gage, A genetic Algorithm for Scheduling and Decomposition of Multidisciplinary Design Problems, *Journal of Mechanical Design*, **118**(4), 1996, pp. 486–489.

Atila Ertas, Professor of Mechanical Engineering, received his masters and Ph.D. from Texas A&M University. He had 12 years of industrial experience prior to pursuing graduate studies. Dr. A. Ertas has been the driving force behind the conception and the development of the transdisciplinary model for education and research. His pioneering efforts in transdisciplinary research and education have been recognized internationally by several awards of Society for Design and Process Science (SDPS). Dr. Ertas established The Academy for Transdisciplinary Learning and Advanced Studies (TheATLAS) as non-profit organizations that fund transdisciplinary research and educational activities. He has developed the Transdisciplinary Master of Engineering and Ph.D. Programs on Design, Process, and Systems in conjunction with the Raytheon Company in Dallas, Texas. This program has graduated over 140 students. Dr. Ertas has written numerous technical papers and modules on transdisciplinary education. He is a Senior Research Fellow of the ICC Institute at the University of Texas Austin, a Fellow of ASME, a Fellow of SDPS, and a Founding Fellow of Luminary Research Institute in Taiwan. He is also an honorary member of International Center for Transdisciplinary Research (CIRET), France. Dr. Ertas has earned both national and international reputation in engineering design. Dr. Ertas is the author of a number of books, among them: A. Ertas, and J. C. Jones, *The Engineering Design Process*, John Wiley & Sons, Inc., first addition 1993 and second edition 1996; A. Ertas, *Prevention through Design (PtD): Transdisciplinary Process*, funded by the National Institute for Occupational Safety and Health, 2010; A. Ertas, *Engineering Mechanics and Design Applications, Transdisciplinary Engineering Fundamentals*, CRC Press, Taylor & Francis Group, 2011; A. Ertas (editor), *Transdisciplinarity: Bridging Natural Science, Social Science, Humanities & Engineering*, TheATLAS Publications, 2011; B. Nicolescu and A. Ertas (editors), *Transdisciplinary Theory and Practice*, TheATLAS Publications, 2013. He has edited more than 35 conference proceedings. Dr. Ertas' contributions to teaching and research have been recognized by numerous honors and awards. The honors and awards include: President's Excellence in Teaching; Pi Tau Sigma Best Professor Award; Pi Tau

Sigma Outstanding Teaching Award; Halliburton Award in recognition of outstanding achievement and professionalism in education and research; College of Engineering Outstanding Researcher Award; George T. and Gladys Hanger Abell Faculty Award for overall excellence in teaching and research; and President's Academic Achievement Award. He also received the most prestigious SDPS George Kozmetsky Distinguished Achievement Award and Excellence in Leadership Award. Most recently, he was recognized as one of the distinguished former students of Texas A&M, Mechanical Engineering Department. He has published over 150 scientific papers that cover many engineering technical fields. He has been PI or Co-PI on over 50 funded research.

Jasmin Rohman is a PhD candidate in Transdiciplinary Design, Process, and Systems at Texas Tech University. She is a Systems Engineer in the Space and Airborne Systems business of Raytheon. She has been the lead Systems Engineer for an Internal Research and Development program focused on secure processing. She is responsible for requirements management and development of Integration Verification and Validation strategies for new business and proposals as well as supporting existing Airborne Processor programs on the F-35, F-22, and F-16 platforms through the design, development, and test phase creating systems engineering work products. She received her Bachelors in Electrical Engineering Cum Laude from the University of Texas at Dallas and a Masters in Engineering Management from Southern Methodist University. Honors include multiple Raytheon Achievement Awards; Raytheon Innovation Award; Raytheon Spotlight on Excellence Awards; Leadership Award from the Chinese Institute of Engineers; Presenter at the Raytheon Information Systems and Computing Symposium; Presenter at the Systems Engineering and Architecture Symposium; TEDxSMU Speaker; and nominated for Six Sigma President Award.

Pratap Chillakanti is a PhD candidate in Transdisciplinary Design, Process, and Systems at Texas Tech University. His research focus is the design and development of a self organized collective intelligence framework for transdisciplinary research, education, and development. Pratap is the founder and CEO of Lensoo Inc. which provides a cloud based collaborative learning and teaching ecosystem. Pratap has provided thought leadership in the high tech industry as a recognized expert in information security, business process automation, and in implementing collaborative knowledge sharing frameworks. Pratap has a BS in EE and MS in Computer Science and Engineering.

T. Batuhan Baturalp, received his B.S. and M.S. degree in Mechanical Engineering from Yeditepe University, Turkey in 2009. Since September 2010, he is a Ph.D. student in Texas Tech University, Lubbock. His current research investigates design of a novel systemic mock circulatory system. He has research interest in health care design including anthropomorphic bipedal walking robots, artificial muscles, and assistive devices. He has extensive research experience in robotics, biomedical and biomechatronic design.