Theory and Methodology for Forming Creative Design Teams in a Globally Distributed and Culturally Diverse Environment

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ABSTRACT

With increased globalization, Internet connectivity, and competitive economic conditions, global organizations are increasingly recognizing the importance of effective global collaborations. Hence, there is a need to extend the use of psychological teaming strategies for domestic team-formations to also accommodate teams that are globally distributed. Previous research efforts have investigated psychological factors for design creativity and effective global collaboration; however, few have addressed these factors concurrently. The focus of this dissertation is therefore on the formation of creative design teams in a globally distributed and culturally diverse environment.

This dissertation provides a theoretical foundation for teaming methodologies for globally distributed and culturally diverse teams. It also presents a new global collaborative and creative design team formation method: the *Global Design Team Formation* (GDTF) method. This is a novel computational method that uses potential team members' psychological and cultural traits, in an attempt to form effective teams that are psychologically and culturally cohesive. The method is based upon and merges Jung's theory with the theoretical frameworks of (a) Teamology and (b) Global Leadership and Organizational Behavior Effectiveness (GLOBE), and it provides a quantitative representation scheme combining scores from the Meyers-Briggs Test Indicator (MBTI) and the Kogut and Singh index (KS index) using the GLOBE dataset.

The GDTF method has been applied to three populations. The control group consisted of 42 three-person teams in a sophomore-level mechanical engineering design course at a US university, to validate the Teamology framework, which is based on Jung's and Belbin's theories. The GDTF method was then applied to two international teaming situations: a globally team-taught course on engineering design at the senior and graduate levels with 8 globally distributed teams across the US, Germany, Mexico, and China; and 23 dyadic teams of US undergraduate students performing automotive research with German graduate students in Germany.

Results of this research shows that psychologically balanced and cohesive teams provide improved design creativity, and that this performance difference can be predicted using the team members' psychological traits. Statistical analysis indicates that creativity in engineering design depends on the presence of Te, Fe, Fi, and Si psychological traits, in decreasing order of importance, within the teams. The importance of these traits remains dominant in global teams, though global diversity negatively impacts team cohesiveness and hence their effectiveness, though not their creativity.

Dedication

To my dearest wife, Tae-Eun Kim, and my precious sons, Ryan Se-Jin Park and Brandon Chan-Woong Park.

To my loving parents, Sang-Chang Park and Sook-Ja Park.

To my late grandmother, Yong-Sik Kim, and my blessed aunt Su-Gil Park.

To my late father-in-law, late Yong-Bok Kim, and my supportive mother-in-law, Joong-Soon Choi.

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Chapter 1

Introduction

1.1 Preface

With increased globalization, Internet connectivity, and competitive economic conditions, global organizations are increasingly recognizing the importance of effective global collaborations. Hence, there is a need to extend the use of psychological teaming strategies for domestic team-formations to also accommodate teams that are globally distributed. Previous research efforts have investigated psychological factors for design creativity and effective global collaboration; however, few have addressed these factors concurrently. The focus of this dissertation is therefore on the formation of creative design teams in a globally distributed and culturally diverse environment.

This dissertation provides a psychological perspective on design creativity in the area of global collaborative engineering. This study, furthermore, focuses on the effectiveness of teams consisting of geographically and culturally diverse members. It investigates what types of cognitive modes have positive correlation to team creativity, and it explores the use of newly developed psychological teaming methods in a global setting. Using the resulting findings, this study develops new teaming technique that produces effective, globally distributed, collaborative, and creative design teams. Finally, this study develops a new creativity index, the Park Creativity Index (Park CI), to anticipate team creativity for mechanical engineering teams.

The psychological perspective on design creativity is seldom considered in engineering design. However, doing so has the potential to lead to a fundamentally new approach on how to select engineers for team membership so as to promote increased creativity for product innovation. Of particular interest, due to the increasing globalization of the engineering economy, will therefore be to investigate the impact of geographical and cultural diversity on such approaches to teaming.

Through this research, the *Global Design Team Formation* (GDTF) method was developed to form teams with a geographically distributed and culturally diverse memberships that work effectively and that demonstrate increased creativity in engineering design. In order to better understand the GDTF method, its core foundations—creativity, cross-functional teams, and global collaboration—are briefly discussed in the subsections that follow. This is then followed by a brief overview of applying the psychological approach to global collaboration, and its application in the form of Teamology in a global setting.

1.1.1 **Creativity**

Design creativity and product innovation are critical for a corporation to it to attain a dominant market position. Accordingly, scholars have developed various metrics to measure creativity, including during concept generation and selection. Consequently, much research has been conducted to identify the underlying factors of creativity. The following subsection will briefly look at the definition of creativity, the psychological perspective on creativity, and methods for leveraging creativity during idea generation.

1.1.1.1 Definition of Creativity

Sternberg (1988), a pioneer of creativity research, noted concerning creativity, that ″some have even wondered if it exists as a single entity or a class of entities aside from its name.″ Indeed, as can be seen in Table 1-1, the definition of creativity varies between fields due to different connotations. For the purpose of this dissertation, creativity in engineering design refers to the development of innovative products that meets customer needs and product requirements through a repeatable design process: (1) define problems; (2) research customer needs; (3) provide plausible solutions; (4) determine a (best) feasible solution; and (5) produce a prototype (Otto & Wood, 1996).

Creativity is subjective and elusive, which makes it is difficult to measure subjectively and consistently. Product innovation, on the other hand, is easily measureable because it is primarily concerned with originality, novelty, and feasibility of methods, ideas, and products. Therefore, using product innovation as a proxy for team creativity, the resulting team products can be evaluated for innovativeness, which is defined in this dissertation as the extent to which the final products are unique compared to current products that already are on the market.

Table 1.1 Definitions of creativity and their implications on assessment (Treffinger, Young, Selby, & Shepardson, 2002)

Sample Definitions	Emphasis in Definition	Primary Focus	Implications for Assessment *Identify creativity through:*
Fromm, Khatena, MacKinnon	Person	Characteristics of highly creative people	Assessment of creative personality traits
Gordon, Guilford, Mednick, Torrance, Treffinger et al., Wallas	Cognitive process or operations	Skills involved in creative thinking or in solving complex problems	Testing for specific creative thinking and problem solving aptitudes or skills
Maslow, Rogers	Lifestyle or personal development	Self-confidence, personal health and growth; self-actualization; creative context or setting	Assessing personal adjustment, health, and self-image; assessing the climate that nurtures or inhibits creativity
Gardner, Khatena	Product	Results, outcomes, or creative accomplishments	Assessing and evaluating products or demonstrated accomplishments
Amabile, Rhodes	Interaction among person, process, situation, and outcomes	Multiple factors within specific contexts or tasks	Assessing multiple dimensions in a profile, with various tools

1.1.1.2 Psychological Perspective on Creativity

Numerous scholars and researchers have studied the correlation between personality traits and creativity ever since Guilford, a pioneer in the area of psychometric research concerning creativity, first contributed a psychological perspective on design creativity (Gough & Library, 1981; Guilford & Hoepfner, 1966; Sternberg, 2006; Torrance, 1987; Treffinger et al., 2002). Today there are two main approaches to assessing creativity: One is based on personality types; the other is based on cognitive processes.

The Meyers-Briggs Test Indicator (MBTI) and the Kirton Adaption Innovation (KAI) are examples of methods that provide personality types that have been used to associate with creativity. For instance, Gough (1981) used MBTI to demonstrate that creativity is associated with personality traits (Isaksen & Geuens, 2006). In particular, his work suggests that creative individuals tend to be, in decreasing order of importance, more intuitive (N), perceiving (P), extrovert (E), and thinking (T). The strong presence of intuitiveness among creative individuals has since been confirmed by 26 other studies (Myers & McCaulley, 1992).

On the other hand, as an example of assessing creativity via cognitive processes, Torrance believed that individuals having divergent thinking are more likely to produce diverse ideas and thus contribute positively to creative thinking. Based on Guilford's work, Torrance therefore developed the Torrance Tests of Creative Thinking (TTCT) to measure individual′s divergent thinking and potential for creativity. The TTCT remain today the most widely used assessments for creative talent (Sternberg, 2006).

1.1.1.3 Concept Generation for Creativity

Viewing creativity from a psychological perspective, Treffinger et al. (2002) have revealed that metaphorical and divergent thinking have positive correlations to the generation of creative ideas. Idea generation is another approach to promote creativity and has been vigorously studied in engineering design. The underlying goal of idea generation is to develop as many ideas as possible with the hopes that implausible interim ideas might subsequently spawn a successful idea.

Generally speaking, concept generation falls into two categories: directed (or logical) and intuitive methods (Shah, 2003). See Table 1.2. Directed concept generation is systematic decomposition and analysis of the problem to search for a design solution. Directed methods generate ideas from physical principles and insights. Intuitive methods, on the other hand, rely on a divergent thinking process to generate more ideas. Examples include Brainstorming, Progressive Methods (6-3-5, C-sketch, Gallery Method), and Morphological Analysis. Both directed and intuitive methods have their advantages and disadvantages, and there is not a single-best idea-generation method for new product development (NPD). Some researchers therefore promote the combination of concept generation methods for increased performance (White et al., 2012).

Table 1.2 Types and names of concept generation methods (Shah, 1998)

Concept Generation Methods	**Intuitive**	Brainstorming, Synectecs, Progressive, Sequential
		Morphological Analysis, Action-Verbs, Check Listing
	Directed (Logical)	Design Catalogs, TRIZ, Inversion, Forward Steps, Factorization and Combinations, Axiomatic Principles

1.1.2 **Cross-Functional Teams**

New product development (NPD) is being challenged by the globalization of markets and the explosive growth of the Internet. Engineers and designers are challenged to balance the economic scales for global products with local customer needs, and new team organizations and team work-patterns are emerging to address these challenges and opportunities. Consequently, cross-functional teams composed of globally distributed and culturally diverse members are increasingly becoming the norm in NPD.

1.1.2.1 Cross-functional Team Effectiveness

The value of a cross-functional teams in new product development is undeniable (McDonough III, 2000). Studies on team effectiveness indicate that cross-functional teams, in which individuals from various areas collaborate with each other, are essential (Carmel, 1995; Griffin, 1997a; Gupta & Wilemon, 1990). More recent meta-studies also emphasize the importance that cross-functional teams are composed of members with diverse skills in multiple functional areas (McDonough III, 2000).

On the other hand, studies on correlation analysis between team performance and the use of cross-functional teams have mixed results (Adler, 1995; Clark & Wheelwright, 1992; Cooper & Kleinschmidt, 1994; Dougherty, 1992; Ford & McLaughlin, 1992; Griffin, 1997b; Gupta & Wilemon, 1990). While some studies have stressed the positive aspects of cross-functional teams for NPD (Dougherty, 1992), others have remained skeptical regarding their effectiveness (Ancona & Caldwell, 1992; Clark & Wheelwright, 1992).

1.1.2.2 Factors Leading to Successful Teams

Scholars have identified several underlying factors for improving teamwork and team effectiveness. Hackman (1987, 1990, 2002) claims that team effectiveness can be achieved through clear role assignments, team composition with competent members, well-organized resources, and rewards. Chen and Lin (2004) identify five essential characteristics for successful teams: functional expertise, experience in teamwork, communication skills, flexible task assignment, and personality traits.

On the other hand, scholars have also identified that problems in cross-functional teams frequently stem from differing working disciplines, cultures, and goals (Hackman & Oldham, 1975; Song & Parry, 1992). Bhadury et al. (2000) stress that heterogeneity of individuals maximizes members′ diversity in a cross-functional team.

1.1.3 **Global Collaboration**

With the rise of global virtual collaboration in global organizations and corporations, cultural diversity (i.e., with members from different cultural backgrounds) is increasingly affecting team functionality, and usually in a negative way. Skeptics have identified challenges due to differences in culture (Horii et al., 2005; Nayak & Taylor, 2009), institutional and disciplinary norms (Mahalingam & Levitt, 2007; Orr & Scott, 2008), and languages (Nayak & Taylor, 2009). One would also expect that the problems of defection (non-cooperative behavior) and deception (lying) with computer-, video-, and audio-mediated communications (Rockmann & Northcraft, 2008) are disproportionally pronounced within global teams.

On the positive side, McLeod and Lobel (1992) showed that cultural diversity from various standpoints increases creativity and productivity. Through proper team composition and management, the potential of cultural diversity can be realized (Hinds & Kiesler, 2002; Kirkman et al., 2004). Dafoulas and Macaulay (2002) also supported these findings by comparing multi-cultural and mono-cultural teams. Needless to say, these new, global team scenarios also provide many new business opportunities for information and communications technology development (Hossain & Wigand, 2004).

To overcome the challenges of global collaboration, and to leverage their opportunities, researchers have explored novel information and communication technologies (Bell & Kozlowski, 2002; Shachaf, 2008), the leadership role (Dubé & Robey, 2009; Lipnack & Stamps, 2008), effective team compositions (Dafoulas & Macaulay, 2002; Daily et al., 1996; Daily & Steiner, 1998), and knowledge management (Kotlarsky & Oshri, 2005; Malhotra, 2000). Additionally, cultural indexes have been developed to better understand differences within teams based on dominant cultural tendencies (Kirkman & Shapiro, 2001), but have thus far not been used in actual team formation.

1.1.4 **Justification for the psychological approach in global collaboration**

Reviews on creativity, multifunctional teams, and global collaboration, highlight the importance of cognitive and cultural diversity among team members (Jackson et al., 2003; Milliken & Martins, 1996; Williams & O'Reilly, 1998). This dissertation follows this and attempts a psychological approach to forming effective, cross-functional (Chen, 2005; Hackman, 2002), multicultural (McDonough III, 2000) teams. Specifically, this study explores the leveraging of psychological and cultural diversity to compose globally collaborative and creative design teams.

Scholars from a variety of fields have demonstrated the positive correlation between cognitive diversity and creativity (Glick et al., 1993; Kilduff et al., 2000; Miller et al., 1998; Williams & O'Reilly, 1998). In particular, teams with a cognitively diverse membership, fosters a richness of information with broad perspectives as well as different types of information, whereby creativity can be promoted (Wilde, 2008).

Human psychological characteristics and its measurement systems (psychometrics) are universally applicable (Kirby et al., 2007; Schaubhut et al., 2009). One would therefore expect that the positive correlation between cognitive diversity and creativity would apply to multicultural teams as well.

Cognitive and cultural diversity is not without its challenges. Alienation and poor cohesion due to diversity are major causes for poor team performance (Harrison & Klein, 2007; Jackson et al., 2003; Milliken & Martins, 1996; Van Knippenberg & Schippers, 2007). Cognitive diversity is also a frequent cause for task conflicts and relationship conflicts (De Dreu & Weingart, 2003). It is therefore critically important that teams are carefully composed to take advantage of diversity while not needlessly causing problems.

1.1.5 **Teamology in a Global Setting**

Teamology was developed by Wilde (2008) to enhance design creativity using cognitive diversity. Wilde has demonstrated that design creativity is closely associated with psychological characteristics. Others have published meta-research on team formation methods for creativity in engineering design using cognitive diversity (Bannerot, 2007; Felder et al., 2002; Jensen et al., 2000; Otto & Wood, 2000; Trevisan et al., 1999). Still, an important issue remains to be addressed for teams with globally distributed, culturally diverse members: namely, that of team cohesiveness.

As discussed in the previous section, cognitive diversity promotes creativity. On the other hand, this diversity diminishes team cohesiveness. The issue of cohesiveness remains unsettled (Guzzo & Dickson, 1996). The lack of cohesiveness can cause isolation and lack of satisfaction, which one might expect would negatively impact the quality of team performance. However, Wilde (2008) reports of a double blind study where cognitive diversity did indeed reduce cohesiveness but also increased creative performance. The question is how much reduction in cohesiveness can be tolerated before its negative impact outweighs the benefits for cognitive diversity with regards to creativity in design. The challenge of culturally diverse teams is that their added dimension of diversity further reduces team cohesiveness, perhaps beyond the break-even point with regards to the benefits of cognitive diversity and the added insight provided by the cultural diversity.

1.2 Problem Statement

Research on team effectiveness, including in a global context, have thus far pursued psychological and socio-cultural perspectives separately rather than developing an integrated systematic approach. This dissertation will address this issue as follows:

> ***PROBLEM STATEMENT:*** *The objective of this dissertation is to develop a theoretical framework, and an associated novel computational methodology, that facilitate the formation of effective, global collaborative, and creative design teams in mechanical engineering, predicting team performance using individual personality trait measurements and established cultural traits.*

1.3 Research Questions

- What are the primary challenges with regards to team effectiveness in global collaborative design projects? This question will be answered in Chapter 3.

- How can personnel be systematically grouped to form effective, global collaborative, and creative design teams using individual personality trait measurements and established cultural traits? This question will be answered in Chapter 4.

- Extending team formation based on individual personality trait measurements and established cultural traits, how can the proposed methodology be extended to accommodate special, overriding skill sets? This question will be answered in Chapter 5.

- Which personality traits correlate to creativity in engineering design? And can these traits be used to predict team creativity? These questions will be answered in Chapter 6.

- Are the methods developed for creative design team formation, based individual personality trait measurements and established cultural traits, applicable to other datasets? This question will be answered in Chapter 7.

1.4 Solution Overview

The purpose of this dissertation research is to provide a theoretical foundation and methodology for forming high performance, globally distributed, and culturally diverse engineering design teams tuned for creativity. The objective is to use individually measured personality traits (cognitive modes), complemented by established cultural traits and overriding skill sets, to predict team creativity in engineering design. With this computational capability, team formation can be optimized to maximize creativity performance.

The personality traits are measured based on Meyers-Briggs Type Indicator (MBTI), abbreviated based on Teamology theory (Wilde, 2008). The cultural traits are derived from the Kogut-Singh (KS) index (Kogut & Singh, 1988) using the GLOBE dataset (House et al., 2004). The overriding skill sets are accommodated using the Extended Fuzzy Analytical Hierarchy Procedure (EFAHP) by Chang (1996). The team creativity performance is measured using the Innovative Characteristic Metric (ICM) by Saunders et al. (2011).

Three participant datasets are used in this dissertation research:

- ME 2024: 42 three-person teams composed of US sophomore mechanical engineering students are used to establish a correlation between individually measured personality traits and team performance with regards to creativity in engineering design.
- ME 5664: 8 12-person teams, each composed of seniors and graduate students in mechanical engineering from the US, Germany, Mexico, and China, are used to extend the methodology to incorporate cultural traits and overriding skill sets.
- NSF REU: 23 dyadic teams composed of US undergraduate mechanical engineering students and German graduate mechanical engineering students are used to test and validate the above methods.

1.5 Organization of Dissertation

The body of this dissertation has been organized as follows:

Chapter 1 provides an introduction to the problem domain, the problem statement, research questions, and a solution overview.

Chapter 2 presents a comprehensive literature review on psychometrics, team formation methods, socio-cultural frameworks, and creativity assessments.

Chapter 3 discusses how culturally diverse and geographically dispersed members affect overall team performance. Recommendations on how to manage the challenges associated with such teams are presented based on a literature review and on an empirical study.

Chapter 4 introduces a novel computation method, the Global Design Team Formation (GDTF) method, for forming teams with culturally diverse and geographically dispersed memberships, based on individually measured personality traits and established cultural traits. Data sets used: ME 2024 and ME 5664.

Chapter 5 extends the GDTF method to accommodate special, overriding skill sets. Data sets used: ME 2024 and ME 5664.

Chapter 6 correlates personality traits with creativity in engineering design as measured by the Innovative Characteristic Metric (ICM). Based on these findings, a new creativity index, the Park Creativity Index (Park CI) is established for predicting team performance with regards to creativity. Data set used: ME 2024.

Chapter 7 validates the GDTF method using a third data set. Data sets used: ME 5664 and NSF REU.

Chapter 8 presents discussion and conclusion.

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Chapter 2

Literature Review

This chapter reviews previous work in the areas of creativity assessment, team formation, and socio-cultural frameworks. The review of creativity assessments focuses on assessment of idea generation, creative products, and creative individuals. For team formation, the focus is on the Teamology, 6-Hat, and CATME methodologies. Finally, for socio-cultural frameworks, the focus is on the Hofstede Cultural Dimension and the Global Leadership and the Organizational Behavior Effectiveness (GLOBE) project.

2.1 Creativity Assessment

Taylor (1988) summarizes Mooney's four approaches to creativity: the *environment* in which the creation comes about; the *product* of creating; the *process* of creating; and the *person* who is creative. The focus on the environment might include the location, structures, and composition of the participants; the focus on the product measures the creativity by what is produced; the focus on the process of creation looks at methods for that produce creativity; and the focus on the creative person seeks to identify these individuals and combinations of individuals (e.g., in a team). Significant research has been pursued in these areas over the past 50 years since Mooney identified these four approaches (Mooney, 1963).

This dissertation is concerned with Mooney's fourth approach; namely to investigate how to identify creativity in individuals and within teams based on their personality traits and cultural traits. The participating individuals and teams apply standard engineering design processes (Mooney's third approach) and their creativity is measured using their resulting design as a proxy (Mooney's second approach). It does not address the environment in which the creativity takes place (Mooney's first approach).

The following subsections will therefore provide a brief overview of methods for idea generation (ideation), methods for assessing creative products, and methods for assessing creativity based on personality traits.

2.1.1 Assessing Idea Generation (ideation)

Many designers do not invest much energy in idea generation (ideation), but simply move forward with the first idea for a solution that comes to mind. Quickly selecting a solution gives an immediate sense of productivity and that time is not wasted generating ideas that will be rejected. Unfortunately, such process shortcuts increase the risk that better ideas are overlooked. In an increasingly globally competitive world, few corporations can afford to overlook the better ideas and thus fail to bring new products to market that outperform those of the competition. The fundamental premise of idea generation in engineering design is to generate a large number of ideas to reduce the risk that a novel, plausible idea is overlooked—or worse, is subsequently first brought to market by the competition.

A number of methods have been developed to stimulate the generation of creative ideas in engineering design, so as to systematically leverage the creativity of the individuals on a design team, and hence reduce the likelihood that a novel and plausible idea is overlooked. Shah et al. (2003) provides a systematic classification of formal idea generation methods in engineering design:

Intuitive methods use mechanisms to break what are believed to be the mental blocks:

1. ***Germinal methods*** aim to produce ideas from scratch: Morphological Analysis; Brainstorming; and the K-J Method.
2. ***Transformational methods*** generate ideas by modifying existing ones: Checklists; Random Stimuli; and the PMI method.
3. ***Progressive methods*** generate ideas by repeating ideas in discrete repetitive progressive steps: Method 6-3-5; C-Sketch; and the Gallery Method.
4. ***Organizational methods*** help designers generate ideas by grouping them in useful ways: The Affinity Method; Storyboarding; and Fishbone Diagrams.
5. ***Hybrid methods*** combine techniques to address varying needs at different phases of idea generation: Synectics.

Logical methods use systematic decomposition and analysis of the problem:

1. ***History based methods*** use catalogued past solutions: Theory of Inventive Problem Solving (TRIZ).

2. ***Analytical methods*** develop ideas from first principles: Forward Steps; and Inversion.

The metrics presented by Shah et al. (2003) are widely used to evaluate the effectiveness of these idea generation methods. These four metrics are:

1. ***Novelty*** measures how new and unusual the idea is compared to what is expected;
2. ***Variety*** measures the extent to which the ideas generated span the solution space;
3. ***Quality*** how feasible the set of ideas satisfy the customer needs; and
4. ***Quantity*** is simply the total number of ideas that are generated.

For instance, building on these metrics, Oman et al. (2013) present the Comparative Creativity Assessment (CCA) method that effectively merges these four metrics (i.e., ignoring variety and quantity, and blending together novelty and quality to form a singular CCA score). This enabled the CCA method to evaluate individual concepts within a data set to determine the most creative ideas for a given design problem.

2.1.2 Assessing Creative Products

Cognitive psychologists investigating creativity generally consider fluency and novelty as primary measures of ability to generate ideas, though this is inadequate for engineering design (Shah et al., 2003). Engineers must not only generate novel ideas, but also reduce these ideas to practice while satisfying customer needs. Hence, following the idea generation phase (Section 2.1.1), the engineers set aside the notion of creativity and focus on evaluating the concepts to identify those that are plausible, and then select the one best solution that satisfies the customer needs.

In practical engineering design, especially for complex design problems, the design process is not linear. Multiple different idea generation methods might need to be employed to strengthen aspects of the design where novelty is lacking but needed (e.g., to avoid patent infringements). Certain aspects of a design might also need refinement and result in subsequent idea generation to resolve those issues. Often this refinement takes place substantially later after issues have been exposed through detailed engineering analysis. In all these cases, the creativity contained in the initial set of design concepts will differ from the creativity contain in the final product.

Given this complexity and inconsistent variance in where creativity occurs on the timeline of engineering design, even when different design teams are given the same design task, it is not surprising that most metrics for creativity in engineering design focus on the resulting product when assessing the creativity of different design teams (e.g., compare Tables 1 and 2 in Oman et al. (2013)). The product-based creativity assessment also simplifies the evaluation process in that it effectively integrates creativity throughout the engineering design process by not considering creative results that were not used in the final design.

This dissertation research chose to use Innovative Characteristic Metric (ICM) for assessing creativity in engineering design. This metric (Blair & Hölttä-Otto, 2012) is based on a study on the key characteristics of innovative mechanical products (Saunders et al., 2011) relative to products on the market:

Function:

1. Additional function .... ☐Yes ☐No

Architecture

2. Modified size .... ☐Yes ☐No
3. Modified physical layout .... ☐Yes ☐No
4. Expanded usage environment................. ☐Yes ☐No

External interactions

5. Modified material flow .... ☐Yes ☐No
6. Modified energy flow .... ☐Yes ☐No
7. Modified information flow .... ☐Yes ☐No
8. Interaction with infrastructure .... ☐Yes ☐No

User interactions

9. Modified physical demands.................... ☐Yes ☐No
10. Modified sensory demands .... ☐Yes ☐No
11. Modified cognitive demands .... ☐Yes ☐No

Cost

12. Purchase .... ☐Yes ☐No
13. Maintenance .... ☐Yes ☐No

In essence, for each design solution, the rater simply checks off each of these 13 characteristics where the design improves on products in the market place. The ICM score for a design is therefore simply the count of these check marks, thus giving the design solution an integer score in the range [0,13].

The ICM scoring method has been shown to have a higher inter-rater reliability than methods where the rater evaluated originality and/or feasibility (Blair & Hölttä-Otto, 2012). This metric is also more suited to diversity in design solutions than, for instance, the metrics by Shah et al. (2003) that require functional weight factors for the importance of predefined functions (e.g., thrust, medium of travel, motion) and design stages (e.g., physical principles, conceptualization, embodiment, development of detail, testing) to be set *a priori*. That is, ICM is easier to implement and can capture innovative solutions that an assessment designer implementing the Shah et al. (2003) metrics might not have considered.

2.1.3 **Identifying Creative Individuals**

This dissertation research is primarily concerned with predicting creativity using personal and cultural traits, both of the individuals and their combination within a team. This aligns with Mooney's first approach to creativity (1963). There are a large number of methods assessing the creativity of a person or personality (Oman et al., 2013). Four of the more prominent methods in this regard are: Myers-Briggs Type Indicator (MBTI); the Torrance Tests of Creative Thinking (TTCT); the Kirton Adaption-Innovation Inventory (KAI); and Teamology.

The Myers-Briggs Type Indicator (MBTI) is well known as an instrument to assess and identify a person's dominant personality types (Myers & McCaulley, 1992), based on the early work by Jung (1939). These personality types are describes along four dimensions: **E**xtraversion (E) vs. **I**ntroversion (I); **S**ensing vs. i**N**tuition (N); **T**hinking (T) vs. **F**eeling (F); and **J**udging vs. **P**erceiving (P). A person's personality type would therefore be described as combination of these the dominant types, listing the vectors in the order shown: EI → SN → TF → JP. Examples include: ESTJ, ISFP, INTP, etc.

Concerns surrounding MBTI include: (a) personalities not captured by the EI, SN, TF, and JP dimensions (Comrey, 1983; Sipps et al., 1985); (b) biased gender weighting (Myers et al., 1985); and (c) the repeatability of the personal type over time (Carskadon, 1977; McCarley & Carskadon, 1983).

As such, MBTI does not measure creativity, but several researchers have attempted to correlate the MBTI personality types with a person's potential to be creative. An example of this is the Gough Creativity Index (Gough CI) (Gough & Library, 1981); often referred to as the MBTI-CI:

$$\text{Gough CI} = 250 + 3N + P + E + 0.5T \qquad \textbf{Eq. 2.1}$$

In essence, this index suggests that a creative person tends to have a personality dominated by intuition, perceiving, extraversion, and thinking, in declining order of importance. Hence the ideal creative person, according to this index, would have an ENTP personality, dominant in all these four types.

The Kirton Adaption-Innovation Inventory (KAI) offers an alternative to MBTI by indicating a person's creativity potential along a single personality trait dimension: Adoption vs. Innovation. Both KAI and MBTI measure *styles* (binary scales), as opposed to the Gough CI measuring *levels* (graduated scales). Kirton (1976) asserts that MBTI can only be used to capture creativity in the context of innovation and not in the context of adaption. In this context, adoption includes: adapting, improving, advancing, or finding a new application for existing process or product. Isaksen et al. (2003) found that KAI has a significant and positive correlation with the N and P preferences in MBTI (i.e., the SN and JP dimensions), and no significant correlation with the EI and TF dimensions. This is consistent with the N and P preferences in the Gough CI, but misses the contributions by the E and T preferences.

The Torrance Tests of Creative Thinking (TTCT) is widely used to test for divergent thinking and other problem-solving skills (Torrance, 1987). The original TTCT scored creativity on four scales: fluency (number of responses), flexibility (number of categories of responses), originality (rarity of the responses), and elaboration (detail of the responses). It has since been expanded to include 13 more measures: emotional expressiveness, story-telling articulateness, movement or actions, expressiveness of titles, syntheses of incomplete figures, synthesis of lines, of circles, unusual visualization, extending or breaking boundaries, humor, richness of imagery, colorfulness of imagery, and fantasy. The TTCT provides a measure of *level* and not a measure of *style* such as MBTI. More importantly, TTCT measures the creativity potential of a person using a standard instrument with standardized assignments. It is therefore not applicable to evaluate the creativity of a design.

Scoring a person using MBTI or TTCT is time consuming. Typically it takes a person about 35 minutes to complete the 95 MBTI yes/no questions, and about 45 minutes to complete the TTCT exercises. This makes it challenging to ensure a high participation rate unless the person is compensated. Wilde (2008) addressed this problem by designing a simplified set of 20 ″A-B-both-neither″ questions to produce a close approximation to the MBTI personality trait scores. This abbreviated instrument can easily be completed in less than 5 minutes, well before a participant would get restless and withdraw from the assessment. This brevity is an important quality when administering the instrument to a large number of participants or online.

There does not appear to be any published study showing the correlation between the Teamology and MBTI scores. Rather, it is assumed that the Teamology instrument is, by design, closely related to the highly validated MBTI instrument, and therefore must implicitly share a similar validity (Wilde, 2007). Here is an example of a pair of MBTI yes/no questions being merged into a single Teamology question:

> Initiating: People at this pole get pleasure from mingling with others in large or small gatherings. …
>
> Receiving: People at this pole are much more comfortable letting conversations come to them than initiating contact. …

The corresponding Teamology question emerged by substituting "initiating" with "social" and "receiving" with "reserved," where the subject circles (1) "sociable", (2) "reserved", (3) both, or (4) neither:

You are more: (e) sociable (i) reserved

Wilde then uses the Teamology scores in place of MBTI scores to seed the team creation process following two basic principles: First, seed each team with the highest possible Gough CI score available; and then fill the teams such as to maximize personality type diversity within the team (Wilde, 2007). Wilde reports tremendous success in improved mechanical engineering student team performance using this team formation approach (2007, 2008). The following section will discuss this further.

2.2 Team formation methods

A number of team formation methods have been developed. The following three systematic methods have been used extensively in engineering design education: Teamology, 6-Hat, and CATME. The first two are based on psychometrics, while the last one focuses on demographics.

2.2.1 Teamology

As described in Section 2.1.3, Wilde (2007) developed an abbreviated version of the highly validated MBTI instrument, reducing the number of questions from 95 MBTI yes/no questions to a simplified set of 20 ″A-B-both-neither″ questions (Figure 2-1). The 20 questions are distributed into five questions for each of the four dimension: E⇔I, J⇔P, S⇔N, T⇔F. The choice of five questions was chosen to reflect the approximate 80% consistency over time in measured personality traits (Kirby et al., 2007), thus providing the assumption that the raw score within a dimension for a person would only vary by one over time. Wilde thus estimates the scores for these four dimensions as follows:

(1) The subject may for each question select the first work, the second, word, both words, or neither word.

(2) For each dimension, the number of first words and the number of second words are tallied, and the difference of these two tallies is recorded. Thus, for instance, the first five questions in Figure 2-1 will yield an EI score in the range of [-5,5], which maps to the range [(100%I, 0%E), (0%I, 100%E)] with increments of 10 percentage points. This is repeated for the JP, SN, and TF scores.

Based on the work by Jung (1939), MBTI identifies eight cognitive modes (Myers & Myers, 1980). Four of these modes {ES,EN,IS,IN} are associated with he collection of information [C-mode], and four {ET,EF,IT,IF} are associated with decision making [D-mode]. Wilde (2008) developed a computational method to compute these eight modes from his EI, JP, SN, TF scores based on *Jung's Complementarity Rule* that E+I = J+P = S+N = T+F = 0, as shown in Table 2.1.

Energy Direction: Outward or Inward

EI1	You are more:	(e) sociable	(i) reserved
EI2	You are more:	(e) expressive	(i) contained
EI3	You prefer:	(e) groups	(i) individuals
EI4	You learn better by:	(e) listening	(i) reading
EI5	You are more:	(e) talkative	(i) quiet

EI difference: $\sum e - \sum i$ **= EI___**

Orientation: Structured or Flexible

JP1	You are more:	(j) systematic	(p) casual
JP2	You prefer activities:	(j) planned	(p) open-ended
JP3	You work better:	(j) with pressure	(p) without pressure
JP4	You prefer:	(j) routine	(p) variety
JP5	You are more:	(j) methodical	(p) improvisational

JP difference: $\sum j - \sum p$ **= JP___**

Information Collection process: Fact or Possibilities

SN1	You prefer the:	(s) concrete	(n) abstract
SN2	You prefer:	(s) fact-finding	(n) speculating
SN3	You are more:	(s) practical	(n) conceptual
SN4	You are more:	(s) hands-on	(n) theoretical
SN5	You prefer the:	(s) traditional	(n) novel

SN difference: $\sum s - \sum n$ **= SN___**

Decision-Making process: Objects or People

TF1	You prefer:	(t) logic	(f) empathy
TF2	You are more:	(t) truthful	(f) tactful
TF3	You see yourself as more:	(t) questioning	(f) accommodating
TF4	You are more:	(t) skeptical	(f) tolerant
TF5	You think judges should be:	(t) impartial	(f) merciful

TF difference: $\sum t - \sum f$ **= TF___**

Figure 2-1 The Teamology Cognitive Mode Questionnaire (Wilde, 2008)

Table 2.1 Teamology Transformation Formulas (Wilde, 2008)

Collection mode [C-mode]	Decision making mode [D-mode]
ES = EI – JP + 2SN	ET = EI + JP + 2TF
EN = EI – JP – 2SN	EF = EI + JP – 2TF

IS = – EN	IT = – EF
IN = – ES	IF = – ET

Using the Teamology scores for {EI,JP,SN,TF} with range [-5,5], the scores for {ES,EN,IS,IN} and {ET,EF,IT,IF} are therefore in the range [-20,20]. Only the non-negative cognitive modes are recorded and may be scaled from [0,20] to [0,100] for comparison with other measurement methods.

Initially, Wilde (2007) would use the Gough CI score (Equation 2.1) to seed the teams, making sure that each team had a high-scoring individual; and then fill the teams so as to maximize personality diversity within the team.

Later, Wilde (2008) would focus on first identifying the individuals with the highest singular cognitive mode scores (Table 2.1) and use these individuals as seeds. These seeds were identified as probable team leaders. The second person on each team was then selected, from among the set of friends of the leader, but having the most different psychological type score possible. The friendship provides cohesiveness facilitate collaboration, while the psychological type difference provides maximizes the psychological capabilities of the team. For subsequent team members, the focus is entirely on continuing to increase the psychological diversity and associated psychological capability across the team.

More recently, Wilde (2011b) has decoupled the Jungian attitude pairs E-I and J-P into two equivalent decoupled attitude pairs, Ep-Ip for perception (information collection), and Ej-Ij for judgment (decision making). This simplifies subsequent computations (Table 2.2). Based on this new decoupled view, Wilde now seeds the teams with strong Ne scores (ideation) — analogous to the Gough CI score in (Wilde, 2007); and selects the second team members based on a strong Fe scores (community) — analogous to the friend in (Wilde, 2008). For subsequent team members, the focus continues to be on increasing the psychological diversity and associated psychological capability across the team.

Table 2.2 Teamology Transformation Formulas (Wilde, 2011)

Collection mode [C-mode]	Decision making mode [D-mode]
Se = e + p + 2s *experiment*	Te = e + j + 2t *organization*
Ne = e + p + 2n *ideation*	Fe = e + j + 2f *community*

Si = i + j + 2s ***knowledge***	Ti = i + p + 2t ***analysis***
Ni = i + j + 2n ***imagination***	Fi = i + p + 2f ***evaluation***

2.2.2 The 6-Hats based Team Formation Methodology

Much of today′s thinking systems are based on the classical thinking pioneered by Socrates, Plato, and Aristotle about 2,400 years ago. DeBono challenges this rigid, binary process and views instead the brain as a self-organizing information system. Consequently he theorizes six distinct approaches to problem solving and assigns them a representative color (Table 2.3): information (white), feeling (red), caution or discernment (black), optimism response (yellow), creativity (green), and overview (blue). He then proposes the Six Thinking Hats problem-solving strategy (1985): The basic idea is that the entire team ″wear″ the same colored hat for a period of time, looking at the problem from that perspective, before moving on to the next color hat. This approach forces all team members to participate in each stage simultaneously, and it includes all perspectives, validates each approach, and encourages empathy among members as each is forces to examine the problem from other′s perspectives.

Table 2.3 Six Thinking Hats (DeBono, 1985)

Information (White)	The White Hat calls for information known or needed. Considering purely what information is available, what are the facts, and just the facts?
Emotions (Red)	The Red Hat signifies feelings, hunches, and intuition. When using this hat, you can express emotions and feelings, and share fears, likes, dislikes, loves, and hates. Intuitive or instinctive gut reactions or statements of emotional feeling (but not any justification).
Discernment (Black)	The Black Hat is judgment — the devil's advocate or why something may not work. Spot the difficulties and dangers; where things might go wrong. Probably the most powerful and useful of the Hats, but a problem if overused. Logic applied to identifying reasons to be cautious and conservative.
Optimistic response (Yellow)	The Yellow Hat symbolizes brightness and optimism. Under this hat you explore the positives and probe for value and benefit, and seek harmony.
Creativity (Green)	The Green Hat focuses on creativity; the possibilities, alternatives, and new ideas. It's an opportunity to express new concepts and new perceptions, with statements of provocation and investigation, seeing where a thought goes.
Managing (Blue)	The Blue Hat is used to manage the thinking process. It's the control mechanism that ensures the Six Thinking Hats guidelines are observed. What is the subject? What are we thinking about? What is the goal?

Inspired by DeBono′s work, Jensen et al. (2000) developed a team formation method using the Six Thinking Hats classification system as a personality type indicator, much like MBTI is used in Teamology. That is, instead of classifying the participants using MBTI, the participants are classified by which ″Thinking Hat″ they most closely identify themselves with, using a 30-question instrument. Once classified, the teams are formed by ensuring the following dominant ″Hats″ are represented on each team in the following order of importance: (1) Green [creativity], (2) Yellow [optimistic response], (3) Black [discernment], and (4) Blue [managing].

Jensen et al. (2000) and Jensen and Wood (2003) claim that this 6-Hat team formation method works well, especially when merged with an MBTI-based team formation method. For the latter, one of several MBTI-based instruments can be used, including the Keirsey Temperament Sorter (Keirsey, 2007), to classify participants′ personality types. Once classified, the teams are formed by ensuring the following dominant MBTI personality types are represented on each team in the following order of importance: (1)

EN [extroverted intuitor], or IN [extroverted intuitor] but then ensure that someone else on the team is an E [extrovert]; (2) S [sensor]; (3) J [judger]; (4) P [perceiver]; (5) T [thinker]; and (6) F [feeler]. In particular, their results show that teams that satisfied both the 6-Hat and MBTI team formation methods by far outperformed teams that did not with regards to team effectiveness (Jensen & Wood, 2003). The authors, however, do not present strategies or methods for merging these two team formation methods.

2.2.3 **Comprehensive Assessment of Team Member Effectiveness (CATME)**

The Comprehensive Assessment of Team Member Effectiveness (CATME) instrument was developed to facilitate assessment of team effectiveness (Loughry, Ohland, & Moore, 2007). The full instrument consists of 87 questions and is distributed to the individual team members for self- and peer evaluations. A short version consists of 33 questions. These questions investigate five categories associated with team effectiveness: (1) contributing to the team′s work, (2) interacting with teammates, (3) keeping team on track, (4) expecting quality, and (5) having relevant knowledge, skills, and abilities. The primary objectives of this instrument are to (A) facilitate in-project assessment of a team′s effectiveness so appropriate intervention can be applied to improve their performance, and (B) facilitate post-project assessment. The long and short versions of the CATME instrument have been extensively tested, including with sets of 2777 and 1157 students, respectively.

The resulting CATME instrument items suggest a large number of characteristics that would be useful to consider when forming teams. From a practical sense, usually only a few of these characteristics are considered because the complexity of manually balancing a larger set of characteristics becomes impractical. As a result, teams are often self-selected or, at best, balanced using only a limited number of criteria.

To address this challenge, especially in large team-based engineering project courses, Layton et al. (2010) developed the web-based team formation tool, Team-Maker. It permits a course instructor to define a number of criteria he or she wants to consider (e.g., gender, race, special skills, GPA, schedule availability, personality traits), and then have the students complete an online survey on these criteria. Team-Maker will then use a max-min heuristic to determine team assignments using this survey data. The Team-Maker software has been validated by comparing its output to the team assignments generated by experienced faculty members using the same criteria. This validation experiment showed that Team-Maker consistently met the specified criteria more closely than the faculty members.

The integration of Team-Make and the CATME peer review instrument is currently one-directional. That is, teams that are generated by Team-Maker can be used by the CATME peer review system. However, it does not appear to be possible to directly use peer-review results, personality traits, or cultural traits as input to Team-Maker. A work-around might be to have a separate instrument provide results to the students, who then would enter these results into Team-Maker. For instance, by treating creativity as a skill, one might use an MBTI-based instrument to provide the input for computing the Gough Creativity Index (Eq. 2.1), and then have the student enter this index value into Team-Maker as if it was a GPA or previous course grade. The challenge here would be to avoid deliberate or unintentional data entry errors by the students, especially if they do not see the significance of the data values (e.g., MBTI personality type scores).

2.3 Socio-Cultural Framework

Socio-culture framework researchers, starting with Hofstede (1984) and continuing with Schwartz (1994), Smith and Peterson (1988), Inglehart (1997), and House et al. (2002), have clearly shown how differing cultural values and norms significantly affect the quality of team member interactions and team performance in culturally diverse teams. This section will therefore review the groundbreaking work by Hofstede to establish a socio-cultural framework, and the important analysis and extensions of this effort by the GLOBE project.

2.3.1 Hofstede Cultural Dimensions

Hofstede, a pioneer in comparative national-culture studies, conducted between 1967 and 1973, as the manager of the personnel research department at International Business Machines (IBM) Europe, a large-scale project on cultural dimension modeling by analyzing the answers of 117,000 IBM matched employees using the same attitude survey across 50 different countries and three regions. Based on this analysis, Hofstede eventually identified systematic differences in national cultures along six primary dimensions: (1) power distance [PDI], (2) individualism [IDV], (3) uncertainty avoidance [UAI], (4) masculinity [MAS], (5) long-term orientation [LTO], and (6) indulgence versus restraint [IVR]. The last dimension was only recently added (Hofstede et al., 2010), so his work is still most frequently associated with the five-dimension framework (PDI, IDV, UAI, MAS, and LTO) shown in Table 2.4.

Table 2.4 The Hofstede Cultural Dimensions (Hofstede et al., 2002)

Power distance (PDI)	The extent of acceptance of unequal distribution of power. Cultures that endorse low power-distance, expect and accept power relations that are more consultative or democratic.
Individualism (IDV) vs collectivism	The degree to which individuals are integrated into groups. In individualistic societies, the stress is put on personal achievements and individual rights. People are expected to stand up for themselves and their immediate family, and to choose their own affiliations. In collectivist societies, individuals act predominantly as members of a lifelong and cohesive group or organization.
Uncertainty avoidance (UAI)	The society's tolerance for uncertainty and ambiguity. People in cultures with high uncertainty avoidance tend to minimize the occurrence of unknown and unusual circumstances; whereas, low uncertainty avoidance cultures accept and feel comfortable in unstructured situations or changeable environments, and try to have as few rules as possible.
Masculinity (MAS) vs femininity	The extent of emotional role distribution between genders. Masculine cultures' values are competitiveness, assertiveness, materialism, ambition, and power; whereas feminine cultures place more value on relationships and quality of life.
Long-term orientation (LTO) vs short-term orientation	Long-term oriented societies attach more importance to the future, and foster pragmatic values oriented towards rewards, including persistence, saving, and capacity for adaptation. Short-term oriented societies value the past and the present, including steadiness, respect for tradition, preservation of one's face, reciprocation, and fulfilling social obligations.

These dimensions have over the years been empirically verified and shown to be statistically independent, and the associated framework has caught the interest of international business scholars, especially with regards to international marketing and retailing (De Mooij & Hofstede, 2002).

Hofstede′s cultural framework, however, has been subject to critique, in particular with respect to (1) overgeneralization across large, diverse countries, and (2) inconsistent scoring methods across the dimensions (Parboteeah et al., 2005):

With regards to overgeneralizations, Hofstede treats the extremely diverse and large country of China as one, including Macao, Hong Kong, and Taiwan. Indeed, the current Chinese government (PRC) recognizes 51 peoples native to China, each with distinct cultures. Does it make sense to consolidate all these diverse cultures into one? Would one expect that all these cultures would score similarly within the

Hofstede dimensions? After all, Hoftstede's China, Korea, and Japan scores do differ. To put Hoftstede's work in context, in 1967-1973, IBM did not have access to China other than the two, mutually very independent, western-oriented enclaves of Hong Kong and Taiwan. Given the similarity of the Hong Kong and Taiwan scores, and that these two enclaves represented the only accessible regions of China, Hoftstede's merger of their scores at that time seems reasonable. With the dramatic opening of mainland-China these past two decades, it would be interesting to see how accurate Hoftstede's score remains across China, especially given the great importance of China within the world economy. Thus far the results of such an investigation has not been published. Still, by comparing the Hoftstede scores for China (consolidated), South Korea, and Japan, one would not expect the regional Hoftstede scores across China to differ significantly.

A second criticism of the Hofstede dimensions is how the Masculinity (MAS) vs. femininity scores are computed. For all the other dimensions, each of the two directions of the dimension are scored independently. Hence, the scores for any of these dimensions can be derived from a **weak-weak**, **weak-strong**, **strong-weak**, and **strong-strong** combination. However, for MAS, only the Masculinity is measured and the femininity is simply defined as its inverse; hence for MAS scores, only the **weak-strong** and **strong-weak** combinations are possible. This inconsistency in variable independence in the dimension scores is of concern when computing the Hofstede cultural distance index (CDI) between pairs of countries.

2.3.2 Global Leadership and Organizational Behavior Effectiveness (GLOBE)

The Global Leadership and Organizational Behavior Effectiveness (GLOBE) study was launched in 1991 by House (House et al. 2002) to analyze the relationship between societal values and practices, and leadership effectiveness; and to address the limitations of the Hofstede datasets and the associated variable dependence in Hofstede's computations. The number of countries captured was increased, the demographics were broadened beyond the employees of a singular company, and the values were updated to reflect the cultural shifts due to the impacts of vastly increased global commerce.

The GLOBE study builds on Hofstede's research and leading studies by Schwartz (1994), Smith and Peterson (1988), and Inglehart (1997). In particular, the GLOBE framework refines Hofstede's five dimensions into nine dimensions (Table 2.5):

- GLOBE subdivides Hofstede's IDV dimension into two sub-dimensions; institutional collectivism (Collectivism I), and in-group collectivism (Collectivism II).
- GLOBE avoids the problems with Hofstede's MAS dimension (Section 2.3.1) by replacing it with two new cultural dimensions; Gender Egalitarianism, and Assertiveness.
- GLOBE refines the definition of Hofstede's LTO dimension (Future Orientation).
- GLOBE adds the Performance Orientation and the Human Orientation. These are similar to the *Confucian Dynamism* and *Kind Heartedness* dimensions proposed by Hofstede and Bond (1988).

The GLOBE study placed great effort developing a sound data collection methodology. More than 170 researchers from different cultural backgrounds worked on construct definition, construct conceptualization, and on measurement of constructs. New instruments were developed to measure latent constructs where needed. Unobtrusive, seven-step measurement scales were used to avoid questionnaire response bias, and experts translated the instruments from English into other languages to prevent measurement-distortion due to language differences. The instruments were subjected to pilot studies, double translations and bias testing, and bias elimination. In most cases the data collection was conducted by natives or by researchers with extensive experience in those cultures.

There are two different perspectives on culture: *emic* and *etic* perspectives. According to Kottak (2006), emic phenomena primarily focus on specific local phenomena within a culture, while etic phenomena are commonly associated with cultural practices between cultures. The GLOBE study takes an etic perspective on cultures (Javidan et al., 2006).

Terlutter et al. (2006) present a comprehensive comparison between the Hofstede, Schwartz, Inglehart, and GLOBE frameworks, and concludes with that the GLOBE framework represents a more comprehensive framework with a stronger theoretical foundation and a more current dataset. In particular, they emphasize that the GLOBE framework makes a distinction between societal values and societal practices, which the Hofstede framework does not. The strength of the GLOBE framework is that it samples a broader set of industries (GLOBE: financial services, food production, and telecommunications; Hofstede: information technology) and organizations (GLOBE: 951; Hofstede: 1 (IBM)). One weaknesses of GLOBE is its relatively low sample size compared to other studies: 17,300 respondents across 62 cultures, with 90% of the cultures having 75+ respondents. Another weakness is that all the respondents are middle managers, which make extensions to other population groups speculative. This latter problem is similar to that of Hofstede's and Schwatz' datasets.

Table 2.5 The GLOBE Cultural Dimensions (House et al., 2002)

Power distance	The degree to which members of an organization or society expect and agree that power should be unequally shared.
Collectivism I	The degree to which organizational and societal institutional practices encourage and reward collective distribution of resources and collective action.
Collectivism II	The degree to which individuals express pride, loyalty, and cohesiveness in their organizations or families.
Assertiveness	The degree to which individuals in organizations or societies are assertive, confrontational, and aggressive in social relationships.
Gender Egalitarianism	The degree to which an organization or a society minimizes gender role differences.
Uncertainty avoidance	The degree to which members of an organization or society strive to avoid uncertainty by reliance on social norms, rituals, and bureaucratic practices, to alleviate the unpredictability of future events.
Future Orientation	The degree to which individuals in organizations or societies engage in future-oriented behaviors such as planning, investing in the future, and delaying gratification.
Performance Orientation	The degree to which an organization or society encourages and rewards group members for performance improvement and excellence.
Humane Orientation	The degree to which individuals in organizations or societies encourage and reward individuals for being fair, altruistic, friendly, generous, caring, and kind to others.

2.4 Key Observations

This chapter has reviewed the published literature in the following areas:

- Creativity assessment (Section 2.1), including the assessment of ideation, the assessment of creative products, and the identification of creative individuals.
- Team formation methods (Section 2.2), including formation based on Myers Brigs Type Indicators (Teamology), formation based on the Six Thinking Hats classification system, and formation based on specific criteria (Team-Maker and its associated CATME team assessment system).

- Socio-Cultural frameworks (Section 2.3), including the Hofstede cultural dimensions and the GLOBE cultural dimensions.

Based on this literature review, the following observations can thus be made:

- Creativity in engineering design differs from creativity as viewed by cognitive science. The latter emphasizes the generation of ideas, which leads to an emphasis on extraversion and intuition personality traits (e.g., Gough creativity index, Eq. 2.1). However, in engineering design, we seek plausible solutions, which means that the emphasis should probably be on another set of personality traits. This will be confirmed in Chapter 6, which will demonstrate that the judgment, extraversion, and sensing personality traits, in declining order of importance, maximize creativity in engineering design.
- Likewise, because the measure of creativity in engineering design focuses on the design process outcome, it therefore makes sense that one uses an outcome-based metric, such as ICM, for measuring creativity in engineering design.
- The 6-Hat team formation method is concerned with forming teams with members that exhibit diversity in their preferred approaches to solving problems. However, research shows that this approach works best when combined with an MBTI-based approach that also considers the members′ personality traits. This suggests that an MBTI-based approach to team formation is critical (e.g., Teamology), and that the 6-Hat method is better suited as a problem solving strategy the way it was originally design.
- Though the Hofstede framework is highly regarded and broadly cited, the newer GLOBE framework represents an updated revision the Hofstede framework that both addresses its shortcomings and provides newer and more refined measurement data. Hence it makes sense to move forward with the GLOBE framework as a means for understanding the impact of cultural traits on the engineering design process.

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Chapter 3

Global Collaborative Design for Success: An empirical study

Abstract

The purpose of this study is to investigate how culturally diverse and geographically dispersed members affect team effectiveness. To do so, Global Collaborative Design Course (ME 5664) has conducted the class with four other colleges in US, Germany, China, and Mexico. From this course, current challenges are identified in four parts: cultural difference; information and communication technology (ICT) preference; proper leadership styles; and incompatibility of technological infrastructure. Based on observations, recommendations and research directions to promote team effectiveness are presented in this paper.

Keyword: Virtual Team, Virtual Collaboration, Geographically Dispersed Team (GDT), Information and Communication Technology (ICT), New Product Development(NPD), Global Leadership

3.1 Introduction

In continuous technology innovation and market globalization, the importance of organizational innovation and effective global collaboration has dramatically increased in global firms and organizations. As the most likely type of a global virtual team, teams have emerged which consist of globally distributed and culturally diverse members (Hackman, 2002; Kirkman, Rosen, Tesluk, & Gibson, 2004).

As many firms and organizations reach concurrence of opinion about global virtual team necessity, empirical research on global virtual team has been conducted to find key factors leading to success.

Results of experiments have shown that positive (Prasert Kanawattanachai & Youngjin Yoo, 2007; Lipnack & Stamps, 2008) and negative (Dubé & Robey, 2009; Nunamaker Jr, Reinig, & Briggs, 2009) perspectives exist concurrently.

Following effective global collaboration analysis, on the other hand, solutions and alternatives to prior research on team effectiveness have been generated by scholars. Among several suggestions, the importance of Information Communication Tool (ICT) role (Duckworth, 2008; Jarvenpaa & Leidner, 1998), effective team composition (Hackman, 2002; Wilde, 2008), cultural awareness (G. L. Downey et al., 2006; Lucena, Downey, Jesiek, & Elber, 2008), and globally endorsed leadership(House, Javidan, Hanges, & Dorfman, 2002) have been studied.

Therefore, experiments were conducted over two years to observe challenges (obstacles) in global collaboration. The remainder of this paper is organized as follows: first, diverse research approaches with various standpoints in global collaboration will be examined; a newly offered course and assigned engineering design project is presented to see how culturally and geographically diverse members work well; next, observations from this empirical study followed by recommended solutions are provided; as last part, this paper concludes with a future research direction.

3.2 Literature Reviews

Jarvenpaa and Leidner (1998) identified main drivers of global virtual collaboration which are ubiquitous internet technologies, rapidly changing competitive environments, shorter product life cycle, travel restrictions and limited natural resources. As summarized by Joseph (2005), higher labor productivity, more revenue from global offshore outsourcing, and availability of specific technical skills resulted in global virtual collaboration.

Cultural diversity can promote team creativity using diverse standpoints, and team productivity can also increase by 24 hours using this working strategy (Duckworth, 2008; P. Kanawattanachai & Y. Yoo, 2007). Team composed of talented and compatible people regardless of time zone and geographical location can be more flexible (Hinds & Kiesler, 2002; Kirkman et al., 2004). Besides, travel-related expenses, time and stress can be reduced (Feldman & Orlikowski, 2011; Nunamaker Jr et al., 2009). This new type of working pattern, thereby, encourages ICTs' development and provides new related business (Hossain & Wigand, 2004).

In spite of positive potential of virtual collaboration, skeptical perspectives on cultural diversity have been addressed. Cultural difference appears to lead to coordination difficulties (Johansson, Dittrich, & Juustila, 1999; T. Kayworth & Leidner, 2000; Maznevski & Chudoba, 2000; Robey, Khoo, & Powers, 2000) and provides drawbacks in effective communication (Sarker & Sahay, 2002; Van Ryssen & Godar, 2000; Watson, Kumar, & Michaelsen, 1993). Besides, culturally diverse composition teams exhibit a lower level of integration and cohesion (Clark & Wheelwright). Massey, Hung, Montoya-Weiss, and Ramesh (2001) found significant differences in working norms between virtual team members from the United States, Asia, and Europe. Rockmann and Northcraft (2008) represented that typical team characteristics, weakly bonded relationships, and relatively greater autonomy, cause significant risk of opportunism.

Various recommendations have appeared to cope with current challenges. Many scholars have demonstrated that ICTs can play significant role of task coordinator, main communication line, and mediator (Bell & Kozlowski, 2002; Shachaf, 2008). In business administration and economic areas, a significant portion of the research has focused on the leadership role (Dubé & Robey, 2009; Lipnack & Stamps, 2008). In addition, studies on effective team compositions to promote positive cultural diversity have been conducted (Dafoulas & Macaulay, 2002; B. Daily, Whatley, Ash, & Steiner, 1996; B. F. Daily & Steiner, 1998). Other approaches such as Transactive Memory System (TMS), Knowledge Management (KM) (Kotlarsky & Oshri, 2005; Malhotra, 2000), and knowledge coordinates (Prasert Kanawattanachai & Youngjin Yoo, 2007; Rico, Sánchez-Manzanares, Gil, & Gibson, 2008) have been developed.

3.3 Global Collaborative Product Development

GM, Autodesk, HP, Oracle, Siemens have established the Partners for the Advancement of Collaborative Engineering Education (PACE) program to strategically support selected academic institutions (http://www.pacepartners.org/). Under PACE support, Virginia Polytechnic and State University with three other universities (TUD-Germany, SJTU-China, ITESM-Mexico), designed The Global Collaborative Design Course (ME 5664).

The objective of this course is to see how engineering design teams composed of geographically dispersed and culturally diverse team members collaborate well with each other. In addition, this program provides opportunity for engineering students to enrich multidisciplinary working and the global collaboration experiences.

The assigned project in 2010 was to design Electric Networked Vehicle (EN-V) version 2.1 based on V. 2.0 platform, which was announced by General Motors Company in the World Expo 2010 Shanghai. Each team will serve different market places, Asia (China), Europe (Germany), and North America (U.S., Mexico). Thus, design changes to meet customer needs will be required.

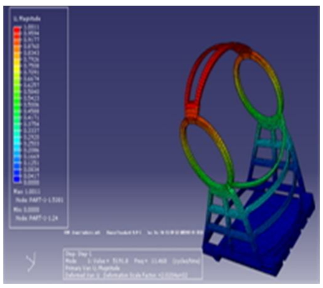
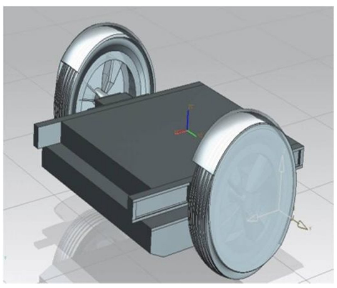
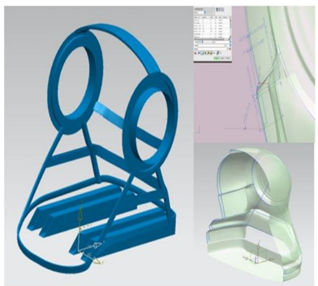
Each team must be composed of geographically dispersed and culturally diverse members and be split into three sub-teams: sub-team A which works on the frame system; sub-team B which develops a linking system; and sub-team C which makes an external storage system. For effective communication between sub-teams, sub-team coordinators were selected and team contact was established.

As the primary device for collaboration, each team will be assigned its own Teamcenter Community (TcC) site and provided Siemens Product Lifecycle Management (PLM) Software NX (formerly Unigraphics), which supports CAD, CAM and CAE for product development. Skype is recommended as the main ICT.

3.4 Procedure and Project Results

Once teams were set up and sub-team members were determined, a schedule was created with all division of tasks for each sub-team to fulfill the project on time. As a major step for product development planning, the survey was generated to investigate the customer's needs in a certain market. Based on the system's specification with the benchmarking research and the costumer's interviews, a Quality Function Deployment was established for analyzing the data from an integrated perspective.

Through engineering design process, each team generated final concepts and outcomes which are summarized in figure 3.1. All three teams provided unique and fresh ideas of EN-V, whereby all teams fulfilled all the requirements from market surveys and engineering analysis. Despite remarkable performance, all participants experienced problems and challenges that previous experiments did not face.

	Adam Opel	Daewoo Patac	GM Buick
Sub-team A			

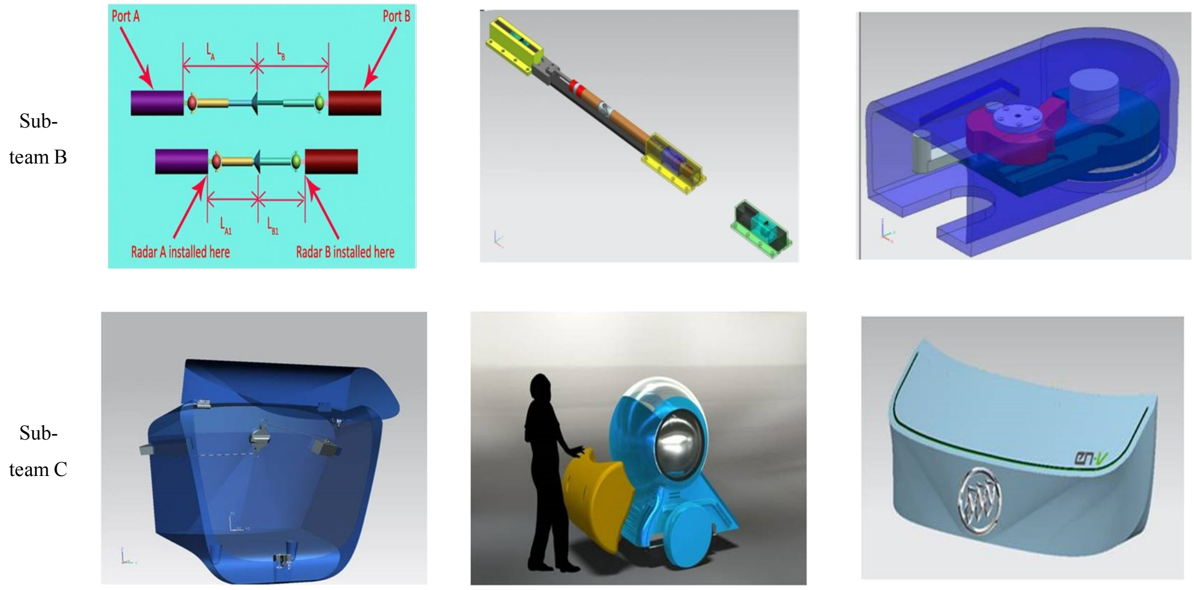


Figure 3-1 Summary of Team Result

***Partners for the Advancement of Collaborative Engineering Education (PACE)**, which links global leading automotive firms such as GM, Autodesk, HP, Oracle, Siemens PLM Software, and their global operations, supports strategically selected academic institutions worldwide to develop the **automotive product lifecycle management** (PLM) team of the future.

3.5 Observation

From this unique opportunity, we summarized our observations into the following: (3.5.1) culture, (3.5.2) preferred Information and communication technology (ICT), (3.5.3) leadership styles, (3.5.4) global leadership, (3.5.5) infrastructures and software.

3.5.1 Cultural Barrier

There is a distinct gap between western and eastern in terms of speaking style. Asian participants have indirect, succinct and passive styles. For instance, Asian students do a lot of thought in advance before they say something. In addition, they are concerned with the fact that their idea is different from other people's thinking. On the contrary, western members have a direct, contentious, and active style. These major differences, which originate from cultural difference, are cause of main virtual collaboration drawbacks.

3.5.2 Information and Communication Technology (ICT) Tools Preference

Information and Communication Technology (ICT) Tools are essential for communication in global collaboration. However, ICT tool preference between asynchronous and synchronous communication styles depends on cultural backgrounds of team members. Asian participants prefer to facilitate asynchronous communication such as e-mail although English speakers have a tendency to use synchronous ICT tools.

All three teams exchanged similar messages and had similar total working hours. Based on observation of effective teams, however, a synchronous communication style is the key to achieve high performance. In contrast, low performance teams have a relatively high portion of asynchronous communication in group meetings. The major drawback was that asynchronous communication style caused delays in response, then schedule delay diminished overall performance.

When ICTs were integrated in team communications, all members reached consensus that either synchronous or asynchronous ICT considerably mitigated cultural difference and supported positive impact on decision-making.

3.5.3 Leadership for Global Collaboration

Much research has demonstrated that group performance is significantly related to the interaction of the leadership style (T. R. Kayworth & Leidner, 2002). The outcome of this experiment also supports that a certain leadership style in global collaboration plays a key role for success. In this study, the impact of leadership behavior in facilitating ICTs and global competence level is conducted.

High performance team leaders put more time in synchronous rather than asynchronous type communication to promote team dynamics. Moreover, effective team leaders encouraged smooth communication among team members through ICTs. In detail, the proportion of synchronous to asynchronous communication in high performance leaders was 58% to 42%, whereas low performance teams had 69% asynchronous to 31% synchronous. In meetings, 95% of members in high performance teams participated in every meeting. Yet, only 61% of members joined regular meetings from low performance teams.

The results also showed that leaders having more global competence tended to work effectively with international team members. Globally competent leaders tried to utilize various ideas from culturally diverse members in the stage of concept generation. Thus, globally competent members could fulfill all customer needs even in abroad market.

3.5.4 Incompatibility Technological Infrastructures and Software

Our study shows that troublesome outcomes will be inevitable if incompatible technological infrastructures and software are not checked at the beginning of the project. Technological barriers are not only from the poor audio signal from geographical distance, but also from the slow internet connections in "Application Sharing," and Teamcenter Community (TcC). This infrastructure barrier depends on the physical distance between the involved countries. One of the main findings in terms of infrastructures was that technological infrastructure can be the crucial factor to choose between asynchronous and synchronous communication in ICTs and engineering software.

With respect to software compatibility and the version unification problem, nobody knew how essential it was to check software compatibility and versions at project launching. This study showed that one team that did not recognize different versions of NX until final assembly failed their tasks.

3.6 Recommendation based on Findings

Based on this empirical study and previous studies, recommendations are discussed in (3.6.1) cultural competence, (3.6.2) global leadership, and (3.6.3) effective ICT applications.

3.6.1 Cultural Competence

The nature of multicultural environment intensifies a typical working pattern in which engineers increasingly work with culturally diverse people (G. L. Downey et al., 2006; Lucena et al., 2008). In practical engineering applications engineers having different cultural backgrounds define and solve problems differently. Therefore, engineers must have high level of global and cultural competence to succeed in global collaboration (G. Downey & Lucena, 2007; G. L. Downey & Lucena, 2004; G. L. Downey, Lucena, & Mitcham, 2007).

3.6.2 Global Leader of Virtues and Strategies

Global collaboration team leaders require a new approach due to unfamiliar patterns of behavior and interaction from virtual environments (Duckworth, 2008). Based on empirical research on global collaboration, the best practices are listed in following. First, leaders set clear objectives and goals for a task because clarity is a crucial part of virtual teams (Hackman, 2002; T. R. Kayworth & Leidner, 2002; Van Sell, Brief, & Schuler, 1981). Second, leaders should choose appropriate ICTs to facilitate team communication which will be foundation of building trust (Bell & Kozlowski, 2002). Third, leaders encourage team members′ engagement and provide guidelines for following team schedules (Yoo & Alavi, 2004). Fourth, leaders allocate tasks fairly and evaluate equally (Jarvenpaa & Leidner, 1998). Finally, leaders should be flexible in team leading because not all teams are the same. Therefore, leaders′ keen insight is the key role even in virtual collaboration.

3.6.3 Effective ICTs Combination and Application

To facilitate rewarding and meaningful ICTs in global collaboration, analysis regarding current ICTs has to be completed. Because of many options of ICTs, leaders have to choose the most effective tools. Of course, the communication style should promote team effectiveness.

Next, even after training members in efficient usage of ICTs, team members must be aware of clarity of the non-verbal and verbal communication. Multiple combinations of ICTs often cause confusion from over-load information. Confusion problem in communication in virtual collaboration is more drastic than traditional face-to-face communication. Thus, to prevent mishaps, members should be clear and highlight important messages rather using vague and overly long explanations.

3.7 Conclusion and Discussion

An academic empirical study was conducted to address current issues on global collaboration. As a result, we had experienced that the performance of global collaboration can range from dismal failures to significant successes. From this empirical study, challenges were summarized as communication difficulty due to cultural differences, unique team dynamics, global leader demand, and infrastructural issues.

Firstly, team members must be aware of fundamental differences in psychological and cultural backgrounds. Besides, facilitation of anonymity for Asian students is a key to encourage member′s participation and encourages honest and efficient communication. Finally, members′ collaborative open mind-set and institutional support by training and education have to be performed in advance.

Secondly, implementing the proper combination of ICTs and encouraging direct messages significantly reduce miscommunication from language difference. Synchronous communication, despite advantages and disadvantages, is a key factor to promote collaboration effectiveness.

Third, team leaders have to compose cohesive teams consisting of various expertise with clear project objectives. Then, effectiveness can be maximized through working arrangements using different time zones and well distributed tasks to all members. Team leader can also promote building up trust among members from continuous monitoring and encouraging member's communication.

Lastly, a technological infrastructure and software availability has to be established at the first stage of project to prevent drawbacks from incompatible technological infrastructures. All the factors affecting virtual team performance are closely connected with each other. From engagement of all factors, we expect to promote virtual collaboration effectiveness.

3.8 Limitation and Future Work

Provided recommendations were limited to suggestion based on empirical research and previous works, because this is a typical and empirical case study. Thus, it is hard to generalize and apply our recommendation to other cases.

Beyond providing ad hoc solutions and encouraging students to become globally competent, a team formation method which allows utilizing cultural diversity in global collaboration has to be studied.

In order to achieve this goal, socio-logical and psychological approaches to developing effective global collaboration team and promoting design creativity are demanded. In addition, universally endorsed leadership style has to be studied for effective management.

3.9 Acknowledgement

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Appendix A

3.5.1.

(Citation): "One of biggest challenges is to catch the point what they really want to say. They are usually very shy and speak indirectly although they have solid mechanical knowledge. It might be from definitely cultural difference. But, honestly, I am used to talk direct way." (10/15/2010)

(Citation): "I really want to try to speak English to our team. But, misunderstanding and miscommunication with western students make me use communication through the email. Communication using email is much efficient for Asian students, because we can clearly transfer our ideas with plenty of time and check spelling by computer." (11/10/2010)

3.5.2

(Citation)" We are aware of the fact that Asian students prefer to use E-mail and this can provide more crisp and clear message. However, in our tight time schedule, best way to resolve problems that we faced is to use SKYPE. Unfortunately, sub-team B sent a mail indicating they have no time until next Tuesday for SKYPE meeting. So, they said "Please send us email for urgent issues, then we will response in shortly." (11/13/2010)

3.5.3

(Citation)" We spent plenty of time on brainstorming due to various ideas. Even though some members still have skeptical perspectives on some issues, those activities actually helped us out producing a fine model in later." (Best performance team, 12/10/2010)

(Citation)"Our kick-off meeting was pretty much going straight forward. So, I assumed that everyone agreed with my ideas and we are on the right track. In later, I figured it out that we're not on the same page. But, it was too late to get back to the point to resolve issues."

(Low performance team, 12/10/2010)

3.5.4

(Citation) "In first couple of meetings, it is hard to arrange Skype meetings with members located in globe. Once we settled down, everybody is on the same page so that everything is going so far so good." (High performance team, 12/15/2010)

3.5.5

(Citation) "We already finished up our sub-team task. Unfortunately, each team has different NX version. But, it is not a big deal to unify NX version. The thing is our linkage system and storage part is interference in bottom space because there is no further discussion in terms of space conflict. So, we have to get to some point and discuss with other sub-teams."(11/25/2010)

(Citation) "My group discovered that the external storage system had been modeled in NX 7.5 while the body, lower chassis and the linkage system were modeled in NX 7.0. Some delays are inevitable for unification of software version until final assembly."(12/07/2010)

Chapter 4

(Manuscript #1) A Novel Computation Method for Forming Global Collaborative and Creative Design Teams

Abstract

This paper presents the novel computation method for forming globally distributed, culturally diverse creative design teams, thereby showing overall procedures and conditions. The objective of this study is to provide a new perspective on how to effectively form a team to promote team creativity using psychological and socio-cultural aspects. To do so, this new method, referred to as the Global Design Team Formation (GDTF), is developed from the Meyers-Briggs Test Indicator (MBTI), through a quantitative representation scheme, and the modified Kogut and Singh index (KS index) using Global Leadership and Organizational Behavior Effectiveness (GLOBE) data set. GDTF not only provides a strategic guideline for utilizing cognitive and cultural diversity, but also shows psychological and socio-cultural perspectives on design creativity and innovation in a global context.

Keywords: Psychological and Sociological Team Formation, Design Creativity and Innovation, Global Collaborative Engineering

4.1 Introduction

With continuous technological innovation and a harsh global economic environment, global collaboration is a key issue to rapidly answer market demands for global firms, through sharing competencies and resources (Hertel, Geister, & Konradt, 2005). A team which consists of globally distributed and culturally diverse members, is the most likely type of organization in global collaboration projects. However, this phenomenon frequently faces unique challenges and conflicts which cause extra cost and poor project performance (Mahalingam & Levitt, 2007; Scott, Levitt, & Orr, 2011). Some researchers, on the other hand, have found that cultural diversity increases creativity and productivity from various standpoints (Cox & Blake, 1991; McLeod & Lobel, 1992). To address problems, effective global teaming and management has been vigorously studied in various areas (Pamela J Hinds & Bailey, 2003; Horii, Jin, & Levitt, 2005; Jung & Sosik, 2002; McDonough III, 2000).

In product design areas in global context, on the other hand, research outcomes show that design creativity and innovation are crucial factors leading to growing economic and business success (Brown & Eisenhardt, 1995; Johne & Snelson, 1988). Many researchers, therefore, have studied underlying characteristics of creative design process and methodology. Intrigued by Guilford′s landmark in the American Psychological Association (Guilford, 1950), especially, research on creativity has been mainly focused on cognitive and personal traits (S. J. Chen & Lin, 2004; Finke, Ward, & Smith, 1992; Goldschmidt, 1991). The explosion of interest in correlation between cognitive diversity and creativity eventually expands to cross-disciplinary collaboration team formation methodology.

Although socio-cultural and psychological perspectives on team forming methods have been conducted respectively, research that concurrently deals with these is very rare. Hence, this paper provides the roadmap for composing the effective global collaborative and creative design team methodology, which can create a synergy effect without compromising performance.

This new method, referred to as the Global Design Team Formation (GDTF) method, has built on, and merged, two well-established theories which are (A) Jungian′s cognitive functional modes and (B) the Global Leadership and Organizational Behavior Effectiveness (GLOBE). Specifically, the method combines scores from the Meyers-Briggs Test Indicator (MBTI), and the modified Kogut and Singh index (KS index). To do so, a quantitative representation scheme is implemented for MBTI and the Global Leadership and Organizational Behavior Effectiveness (GLOBE) dataset is used as the main source of KS index in this study.

4.2 Backgrounds

The theory of psychological types created by C. G. Jung and operationalized by I. B. Myers and K. C. Briggs generated another spectrum of theoretical framework (D.J. Wilde, 2008). To date, the MBTI, one of the most comprehensive instruments for psychological profiling, has been exploited with diverse perspectives in professional educations: investigating underlying characteristic of psychological types for academic achievement (McCaulley 1976, 1981, 1983, 1987, 1990; Myers, McCaulley et al. 1985; Felder and Silverman 1988; Myers and McCaulley 1988), promoting design creativity (Borchert, Jensen, & Yates, 1999; Feland & Jensen, 2000; DD Jensen & Bowe, 1999; D. Jensen, Feland, Bowe, & Self, 2000; D. D. Jensen, Murphy, & Wood, 1998; Y. Kim, McRoy, & Dicker, 2001; Y. S. Kim & Kang, 2003; Y. S. Kim, Kim, & Jin, 2005).

It is noteworthy to mention that the preference of sensing(S), thinking(T), and judging(J) among eight different cognitive modes has a positive correlation with success in engineering (McCaulley 1976, 1983, 1983, 1987; Felder and Silverman 1988; McCaulley 1990; Felder, Forrest et al. 1993). Although these considerably impact engineering, studies have limited analyzing and categorizing factors leading to high performance in engineering. Yet, not many scholars exploit these results in effective engineering team formation strategy.

4.2.1 Wilde′s Team Formation Method (Teamology)

Leading scholars such as D.J. Wilde (2008),and Jensen et al. (1998, 2000) have scrutinized different techniques of forming teams in engineering. Teamology, developed by Wilde for student design teams in Mechanical Engineering Design Divisions at Stanford University, has received attention by winning from The Lincoln Design Award several times over 16 years.

Wilde has successfully demonstrated that engineering design creativity is closely related to a person′s psychological characteristics. The fact that every human has a tendency to find answers using sensing, intuition, thinking, or feeling (Myers & Myers, 1980), leads to modeling the human personality with eight cognitive modes (Table 4.1), which can occur at different levels in people. Based on Jungian theory, Katherine C. Briggs and Isabel Briggs Myers divided human personality into introverted (IS, IN, IT, IF) and extraverted (ES, EN, ET, EF), thereby adding Judging and Perceiving as determining factors. Furthermore, Briggs also claimed that the four modes on the left (ES, EN, IS, IN) are associated with information-collection, called C-Mode, and those located on the right (ET, EF, IT, IF) are linked to decision-making, called D-Mode (Table 4.2). These discriminating C and D modes were also not specified until Briggs and Myers implemented Judging and Perceiving (Myers & Myers, 1980). In detail, someone who has preference of either E and P or I and J is categorized by collect-information mode. On the contrary, someone who has either E and J or I and P is categorized by decision-making mode.

Table 4.1 Eight Cognitive Modes

Extraversion	E	Introversion	I
Sensing	S	Intuition	N
Thinking	T	Feeling	F
Judging	J	Perceiving	P

Table 4.2 MBTI Cognitive Function Modes

Collection Mode		**Decision Mode**	
ES	**EN**	**ET**	**EF**
Extraverted Sensing	Extraverted Intuition	Extraverted Thinking	Extraverted Feeling
IS	**IN**	**IT**	**IF**
Introverted Sensing	Introverted Intuition	Introverted Thinking	Introverted Feeling

Wilde has also applied Jungian theory and Briggs's method to engineering design team formation for promoting design creativity by enhancing the engineering design process: define the problem, gather information, provide plausible solutions, decide feasible solutions, and execute the best solution(K. Otto & Wood, 1996; K. N. Otto & Wood, 1998, 2000). To identify personality, he also developed a survey which consists of 20 questions. The questionnaire variables represented in Figure. 4.1. are grouped as an appropriated conversion formula, shown in table 4.3.

Energy Direction: Outward or Inward					
EI1	You are more:	(e)	sociable	(i)	reserved
EI2	You are more:	(e)	expressive	(i)	contained
EI3	You prefer:	(e)	groups	(i)	individuals
EI4	You learn better by	(e)	listening	(i)	reading
EI5	You are more:	(e)	talkative	(i)	quiet
EI difference: $\Sigma e - \Sigma i = EI$_____					
Orientation: Structured or Flexible					
JP1	You are more:	(j)	systematic	(p)	casual
JP2	You prefer activities:	(j)	planned	(p)	open-ended
JP3	You work better	(j)	with pressure	(p)	without pressure
JP4	You prefer:	(j)	routine	(p)	variety
JP5	You are more:	(j)	methodical	(p)	improvis-ational
JP difference: $\Sigma j - \Sigma p = JP$_____					
Information COLLECTION process: Facts or Possibilities					
SN1	You prefer the:	(s)	concrete	(n)	abstract
SN2	You prefer:	(s)	fact-finding	(n)	speculating
SN3	You are more:	(s)	practical	(n)	conceptual
SN4	You are more:	(s)	hands-on	(n)	theoretical
SN5	You prefer the:	(s)	traditional	(n)	novel
SN difference: $\Sigma s - \Sigma n = SN$_____					
DECISION-making process: Objects or People					
TF1	You prefer:	(t)	logic	(f)	empathy
TF2	You are more:	(t)	truthful	(f)	tactful
TF3	You see yourself as more:	(t)	questioning	(f)	accommo-dating
TF4	You are more:	(t)	skeptical	(f)	tolerant
TF5	You think judges should be:	(t)	impartial	(f)	merciful
TF difference: $\Sigma t - \Sigma f = TF$_____					

Figure 4-1 The Questionnaire Variables

Table 4.3 Conversion Formula

	Teamology (2009)	
	C-MODE	**D-MODE**
Measurement	ES=EI-JP+2SN, EN=EI-JP-2SN, IS=-EN,IN=-ES Where, EI=E-I, JP=J-P,SN=S-N	EF=EI+JP-2TF, ET=EI+JP+2TF, IT=-EF,IF=-ET Where, EI=E-I, JP=J-P,TF=T-F

The main guidelines of Wilde′s team formation method are affinity group and non-duplication. By the rule of affinity, teams can be composed of preferred team members by the request of regular and marginal members. The leaders who have the highest score in each cognitive functional mode will be allocated at the top of each functional group followed by regular and marginal members. Non-duplication is the rule that regular members of a group cannot have the same psychological profile as the leader. The value of marginal group is in covering vacant modes and sharing responsibility for the team role (D.J. Wilde, 2008).

Although Teamology has contributed to team creativity by promoting cognitive diversity, various standpoints and personalities have often resulted in personal conflicts. The example of mechanical engineering professor Nathan Delson and Joan Connell of the psychology faculty at the University of California at San Diego gives more weight to the fact that cognitively diverse teams are vulnerable to isolation and cohesion problems. A global engineering team called super team was also introduced at The International Conference on Engineering Design in 2009. Nonetheless, it has not been tested yet because of communications, scheduling, and organizational difficulties (Douglass J Wilde, 2009).

4.2.2 Researches on Cultural Effect on Global Collaboration Project

Burgeoning globalization remarkably affects team formation strategy, and managing culturally, as well as functionally, diverse teams frequently faces unique challenges. In research areas, the effect of cultural diversity on functional diversity (Jung & Sosik, 2002), in identifying effects from cultural differences (Horii et al., 2005; Nayak & Taylor, 2009), and different institutional norms associated with institutions and disciplines (Mahalingam & Levitt, 2007; Orr & Scott, 2008) have been studied. For culturally diverse teams, culture (Gibson, 1999; Kirkman & Shapiro, 2001) includes the influence of *cultural index* as a team composition variable. Pamela J Hinds and Bailey (2003) and P.J. Hinds and Kiesler (2002) claimed that the potential of cultural diversity can be realized by proper team composition and management. Dafoulas and Macaulay (2002) also support these findings thereby comparing multicultural and mono-cultural teams. Likewise, research on cultural perspective on project performance has been rigorously conducted. Yet, studies on effective team building for globally distributed and culturally diverse engineering design teams have barely been conducted.

To form high performance, globally distributed, and culturally diverse design teams, merge two different theories, providing conflict management (CM) and developing a computational method using a quantitative method are critical.

4.3 Global Design Team Formation (GDTF)

Global Design Team Formation (GDTF) is a computational method which allows composing a psychologically and culturally diverse design team. To do so, GDTF has built on and merged two well-established psychological and cultural theories which are (A) Jungian's cognitive functional modes and (B) the Global Leadership and Organizational Behavior Effectiveness (GLOBE).

The challenge, however, is how two different theories can be linked together GDTF. The fact that cognitive functional characteristic and Myers Briggs Test Indicator (MBTI) are universally accepted as being valid (Kirby, Kendall et al. 2007, Schaubhut, Herk et al. 2009) provides a plausible link-up between GLOBE and GDTF. Furthermore, diverse research on working pattern, preference, type, and style depending on different personality types justify implementing MBTI to GDTF (Quenk, Hammer, & Majors, 2001; Schaubhut, Herk, & Thompson, 2009; Schaubhut & Thompson, 2008).

To sum up, MBTI can play the role of the common denominator for linking two different theories and socio-cultural framework will be used for measuring cultural difference. The following sections present the procedures and conditions for the computational method.

4.3.1 Psychologically Diverse Team

Psychologically diverse teams, which are demonstrated by scholars for creativity, consist of cognitive team leaders and supportive team members. Someone who has the highest score in each cognitive functional mode is eligible as a leader, regardless of nationality. After leaders′ cognitive functionality and nationality are determined, team members are chosen based on the rule of psychological familiarity and cultural similarity with respect to each team leader.

As a Conflict Management (CM), psychological cohesiveness rooted in a personal trait is mainly employed. In order to measure psychological cohesiveness with respect to team leader and among team members, Psychological Relationship Characteristic (PRC) coded by positive, neutral, and negative relations with different combinations of MBTI type is utilized (S. J. Chen & Lin, 2004; S. J. G. Chen, 2005). From PRC, team members who have a relatively high score with respect to the team leader will be nominated to be a serious candidate for the team by the GDTF computational method.

In addition to the role of Conflict Management (CM), PRC meets a requirement of psychological teaming techniques. Specifically, positive relationships of Sensing - iNtuition (S-N) and Thinking -Feeling (T-F) satisfy the need of psychologically diverse teaming. As sociability preference expressed by the extroverts is a great asset to engineering design process and global collaboration. Two extroverts are positively correlated to teamwork. Furthermore, individuals having same personality types in Judging (J) and Perceiving (P) are more beneficial to team cohesiveness and performance.

4.3.1.1 Procedure and Conditions

The same questionnaires and conditions that Wilde has implemented in his research are applied in this study to identify psychological personality. Unlike Wilde, eight different cognitive types (Figure 4.2-(a)) are determined by Briggs method (Figure 4.2-(b)) rather than Wilde's method (Table 4.3) to faithfully follow original MBTI.

		Sensing		Intuition	
		Thinking	Feeling	Feeling	Thinking
Introversion	Judgement (IC)	ISTJ	ISFJ	INFJ	INTJ
		IS	IS	IN	IN
	Perception (ID)	ISTP	ISFP	INFP	INTP
		IT	IF	IF	IT
Extraversion	Perception (EC)	ESTP	ESFP	ENFP	ENTP
		ES	ES	EN	EN
	Judgement (ED)	ESTJ	ESFJ	ENFJ	ENTJ
		ET	EF	EF	ET

Collection Mode		Decision Mode	
Extraverted Sensing (ES)	Extraverted Intuition (EN)	Extraverted Thinking (ET)	Extraverted Feeling (EF)
ES=(e+p)+2s	EN=(e+p)+2n	ET=(e+j)+2t	EF=(e+j)+2f
Introverted Sensing (IS)	Introverted Intuition (IN)	Introverted Thinking (IT)	Introverted Feeling(IF)
IS=(i+j)+2s	IN=(i+j)+2n	IT=(i+p)+2t	IF=(i+p)+2f

Figure 4-2 (a) 16 Different Cognitive Types (b) Briggs Measuring Attitude

Then, opposing paired cognitive functions within each functional domain (Information Collection and Decision Making) has to satisfy "Jungian complementarity," because cognitive functional roles not only differ from each other, but their energy direction of Extraversion (E) and Introversion (I) is also opposite.

According to Jungian's psychological interaction's rule, the four pairs of psychological preferences, which are E-I, S-N, T-F and P-J, are limited in their interaction with each other when two different personalities are compared. Each psychological preference can only be compared to its direct counterpart. For instance, in order to be complementary, the psychological relationship between EN and IS, ES and IN types can be expressed by equation (1). ET & IF, EF & IT can be also represented by equation 4.2.

C-Mode: EN®IS=ES®IN = (i®e) + (j®p) + 2*(s®n)=0 Eq. 4-1

D-Mode: ET®IF=EF®IT = (i®e) + (j®p) + 2*(t®f)=0 Eq. 4-2

where, ® represents relationship between two different personal type

	E	I		S	N		T	F		J	P
E	positive	neutral	**S**	neutral	positive	**T**	neutral	positive	**J**	positive	negative
I	neutral	negative	**N**	positive	neutral	**F**	positive	neutral	**P**	negative	positive

Figure 4-3 Psychological Relationship Characteristic (PRC)

Then, Psychological Relationship Characteristic (PRC), shown in Figure. 4.3, is applied as a condition to solve equations (1) and (2). With PRC condition, the condition of 11 different values is applied to this case among three different resolutions (7, 9, 11 different values). The PRC matrix is normalized by adding the lowest value and dividing by the highest value to objectively compare and combine with other quantitative data sets. The result produces a value between 0 and 1, shown in Table 4.4. ESFP-ENTP, ESTJ-ENFJ, ENFP-ESTP, and ENTJ-ESFJ are ideal matching cases, having the value of 1. In contrast, ISTJ-ISTP, ISFJ-ISFP, INTJ-INTP, and INFJ-INFP are the least ideal cases, having the value of 0.

Table 4.4 Normalized Personal Relationship Scale Table

rank11	rank10	rank9	rank8	rank7	rank6	rank5	rank4	rank3	rank2	rank1
0.00	0.17	0.25	0.33	0.42	0.50	0.58	0.67	0.75	0.83	1.00

4.3.2 Culturally Diverse Team

A culturally diverse team for a global collaboration project can be often composed of members who have different cultural backgrounds. To overcome the situation where globally distributed members have never seen each other before, the members who have the highest cultural similarity with respect to each cognitive functional leader are considered as serious candidates. As a main source of cultural framework to measure cultural similarity, Global Leadership and Organizational Behavior Effectiveness (GLOBE) research data is mainly utilized in this study.

4.3.2.1 Cultural Framework

Since Hofstede addressed cultural difference in terms of five different dimensions, a new paradigm has been established in socio-cultural science research, and been widely utilized in diverse areas. Like research on cultural framework, GLOBE, conducted by Robert J. House and other colleagues, is another large-scale replication of Hofstede′s cultural framework. Moreover, the advantages of GLOBE over Hofstede, which is presented in table 4.4, gives more weight the implementation of GLOBE research data in this study.

Table 4.5 Comparison between Hofstede and Globe Model

Differences	GLOBE Model	Hofstede Model
Time Period	1994-1997	1967-1973
Primary researchers involved	170	1
Respondents	Managers	Non-managers and managers
Organizations surveyed	951	1
Type of organizations	Non-multinational	IBM and its subsidiaries

Industries	Financial and telecommunication	Information technology
No. if societies surveyed	62	72
Analysis	Team effort	Single effort
Project design	US based	Dutch based
No. of cultural dimensions	Nine	Four

Firstly, GLOBE has built on previous research conducted by Hofstede (1984), Schwartz (1994), Smith and Peterson (1988), Inglehart (1997). Secondly, Terlutter's study shows that an updated data set is a more comprehensive resource for national cultural differences, even though culture as represented by values and norms of people is not quickly changed (Terlutter, Diehl, & Mueller, 2006). Thirdly, a major difference from Hofstede's framework is that GLOBE more clearly distinguishes between cultural values (desired values) and practices (frequently observed behaviors) (Terlutter et al., 2006). Fourthly, the GLOBE researchers provide quantitative data from different levels in industries (170 managers), organizations (951 organizations), and societies (62 cultures) for more objectivity. Lastly, three of Hofstede's dimensions, UAI, PDI, and IDV are divided in GLOBE into six dimensions, UAI, PDI, Institutional, In-group Collectivism, Gender Egalitarianism, and Assertiveness.

The GLOBE's nine cultural dimensions are defined by followings:

1. Uncertainty Avoidance is defined as the extent to which members of an organization or society strive to avoid uncertainty by reliance on social norms, rituals, and bureaucratic practices to alleviate the unpredictability of future events.

2. Power Distance is defined as the degree to which members of an organization or society expect and agree that power should be unequally shared.

3. Collectivism I reflects the degree to which organizational and societal institutional practices encourage and reward collective distribution of resources and collective action.

4. Collectivism II reflects the degree to which individuals express pride, loyalty and cohesiveness in their organizations or families.

5. Gender Egalitarianism is the extent to which an organization or a society minimizes gender role differences.

6. Assertiveness is the degree to which individuals in organizations or societies are assertive, confrontational, and aggressive in social relationships.

7. Future Orientation is the degree to which individuals in organizations or societies engage in future-oriented behaviors such as planning, investing in the future, and delaying gratification.

8. Performance Orientation refers to the extent to which an organization or society encourages and rewards group members for performance improvement and excellence. This dimension is similar to the dimension called Confucian Dynamism by Hofstede and Bond (1988).

9. Finally, Humane Orientation is the degree to which individuals in organizations or societies encourage and reward individuals for being fair, altruistic, friendly, generous, caring, and kind to others. This dimension is similar to the dimension labeled Kind Heartedness by Hofstede and Bond (1988).

(Definition brought from House, Javidan, Hanges, and Dorfman (2002))

4.3.2.2 Cultural Difference

Using this qualitative as well as quantitative data, many scholars have put their efforts into numerically describing cultural difference. Among various efforts, Kogut and Singh have achieved development of the new index to measure cultural difference, thereby adding a deviation of each dimension from Hofstede's cultural framework (Kogut & Singh, 1988). To date, the KS index is the most dominant method in foreign investment and multinational firms in international business (IB).

Kogut and Singh's (1988) Formula

$$\sum_{i=1}^{n}\{(I_{ij} - I_{iu})^2/V_i\}/n \qquad \text{Eq. 4-3}$$

Where:

I_{ij}: *Index for the ith cultural dimension and j th country*

V_i: *Variance of the index of the ith cultural dimension*

u: Indicates the United States

n: Number of Cultural Dimensions (CD)

Hence, the modified KS index is also implemented as a main guideline of cultural similarity. The reason why I referred to it as the modified KS index is that I have inverted the traditional KS index for measuring cultural similarity. Secondly, GLOBE's dimensions for following information are exploited instead of

Hofstede′s dimensions, which were originally implemented in Kogut and Singh′s index. Lastly, unlike the original KS index, the modified KS index uses the nationality of each cognitive leader as a reference point for measuring cultural similarity.

The variance of each dimension makes the cultural distance index more accurate. Especially, the higher the variance is, the greater the span of values is in each dimension. For instance, the KS index between U.S. and Australia is 0.11, which is one of the lowest values among 91 different countries. It can be treated as the most culturally similar country to the US.

Table 4.6 Kogut-Singh Index Example

couname_first	uncsa_mean	futsa_mean	powsa_mean	indsa_mean	humsa_mean	achsa_mean	Trisa_mean	malsa_mean	aggsa_mean	Kogut Singh
USA	4.15	4.15	4.88	4.20	4.17	4.49	4.25	3.34	4.55	
Australia	4.39	4.09	4.74	4.29	4.28	4.36	4.17	3.40	4.28	0.11

4.3.3 Combination of Quantitative Data for the Computational Method

For effective employment, each component leading to success for cognitively and culturally diverse teams has to be combined. Psychological Relationship Characteristic (PRC), which is universally validated and culturally consistent, is the core of the computational method. PRC, therefore, can be a best solution for a globally distributed team forming tuned for psychological cohesiveness. Then, cultural similarity and unique relationship combination index terms play a role in the average of total score. Especially, once each cognitive leader is determined, the equation 4.4 provides an individual score of GDTF with respect to the cognitive leader and recommends psychologically and culturally well matched members with a single score. Once the pool of serious candidates is ready from the equation 4.4, the second formula checks team score having a better result. By doing so, effective engineering design team can be formed.

4.3.3.1 Candidates Pool

Equation 4.4, which consists of Psychological Relationship Characteristic (PRC) and cultural similarity, provides a score to represent how candidates are well with each cognitive leader. From individual psychological traits, PRC checks psychological cohesiveness with respect to each leader and cultural similarity comes from the inverse of Kogut and Singhs′ cultural difference index to check cultural traits.

As a result, a pool of serious candidates, psychologically well matched and culturally similar to each cognitive leader, can be established through this formula.

$$\underset{\text{personal value w.r.t. each cognitive leader}}{\underline{GDTF}} = MAX \frac{\left[\sum_{i=1}^{n} \boldsymbol{\omega}_{c,j}\boldsymbol{\omega}_{c,l}\right] * \left[\sum_{i=1}^{n}\{1-\left(I_{i,j}-I_{i,l}\right)^2/(V_i * n)\}\right]}{\sum_{k=1}^{m}\left[\frac{m!}{2!(m-2)!}\right]} \quad \text{Eq. 4-4}$$

Where:
I_{ij}: *Index for the ith cultural dimension and j th country*
I_{il}: *Index for the ith cultural dimension and leaders*
V_i: *Variance of the index of the ith cultural dimension*
n: Number of Cultural Dimensions (CD),i.e. n=9
$\omega_{c,j}\omega_{c,l}$: *Personal relationship characteristic factors between ith sub-team from c cognitive functional mode and l th(leader) from c cognitive functional mode*

4.3.3.2 Final Team Selection

Not only is obtaining a pool of serious candidates for a leader important, relationships among team members are also critical for effective teamwork. To seek people who are psychologically and culturally well-matched within a candidate pool, equation 4.5 is used.

$$\underset{\text{team value}}{\underline{GDTF}} = MAX \sum_{k=1}^{m-1}\sum_{j=1}^{m-k}\sum_{i=1}^{n} \frac{\left[\{1-\left(I_{i,j+k}-I_{i,j+k-1}\right)^2/(V_i * n)\} * \boldsymbol{\omega}_{c,j+k}\boldsymbol{\omega}_{c,j+k-1}\right]}{\left[\frac{m!}{r!(m-r)!}\right]} \quad \text{Eq. 4-5}$$

Where:
$I_{i,j+k}$: *Index for the ith cultural dimension and j+k th member's country*
$I_{i,j}$: *Index for the ith cultural dimension and j th member's country*
V_i: *Variance of the index of the ith cultural dimension*
n=9: Number of Cultural Dimensions (CD)
m: Number of sub-team members
r=relationship, e.g. r=2 default
$\omega_{c,j+k}\omega_{c,j+k-1}$: *Personal relationship characteristic factors between j+k th (sub-team) from c cognitive functional mode and j+k-1 th (sub-team) from c cognitive functional mode*

4.4 Illustrative Example

Mechanical engineering at Virginia Polytechnic and State University, has offered the Global Collaborative Design Course (ME 5664) with many universities around the globe. This course is typically designed for competition between teams consisting of cross-cultural students with specific requirements for a certain design topic. The objective of this course is to look at team dynamics and enhance team creativity from cultural diversity. Industrial designers, especially, have joined this program to increase productivity and to explore interdisciplinary synergy.

There are 41 students enrolled in this course in 2013, and they are split into four teams consisting of 10-11 students. Table 4.7 presents the final list of the global project team in 2013. Team 3, targeting the

German market, has two German, six Chinese, four US and two Mexican students. The leader (a45), located at the top of the list, was selected from within the pool of German students, having highest cognitive functional mode score among them. Then, team member were determined by applying the first formula.

Table 4.7 Team Composition Result from Multi-National Group

Team 1 : Chevrolet (MEX)			Team 2: BUICK (US)			Team 3 : Opel (GER)			Team 4: Daewoo PATAC (CHN)		
a5	SJTU	structure	a29	VT	structure	a45	TUD	structure	a37	SJTU	structure
a53	SJTU	structure	a54	VT	structure	a31	TUD	structure	a50	VT	structure
a9	TUD	structure	a19	MTY	structure	a59	TUD	structure	a27	TUD	structure
a4	TUD	structure	a1	MTY	structure	a41	VT	structure	a26	TUD	structure
a15	MTY	Exterior	a43	HU	Exterior	a25	VT	structure	a17	MTY	Exterior
a34 (I.D.)	MTY	Exterior	a44	HU	Exterior	a23	SJTU	Exterior	a58 (I.D.)	MTY	Exterior
a32	VT	Exterior	a7	TUD	Exterior	a8	SJTU	Exterior	a38	VT	Exterior
a13	VT	Exterior	a35	TUD	Exterior	a20	MTY	Exterior	a42	VT	Exterior
a18	TUD	Interior	a16	SJTU	Interior	a30 (I.D.)	MTY	Exterior	a49	SJTU	Interior
a46	TUD	Interior	a51	SJTU	Interior	a47	HU	Interior	a12	SJTU	Interior
						a40	HU	Interior			

*I.D.: Industrial Designer

*TUD: Technischen Universität Darmstadt, HU: Howard University, VT: Virginia Tech, MTY: Monterry Tech, SJTU: Shanghai Jiao Tong University

*See Appendix A and B for MBTI results and Country information

4.5 Conclusion

This study presents the novel computation methodology, referred to as Global Design Team Formation (GDTF) method to form global collaborative and creative design teams. With the frame of a psychological teaming method (Teamology), two well-established psychological and cultural theories, which are (A) Jungian′s cognitive functional modes and (B) the Global Leadership and Organizational Behavior Effectiveness (GLOBE), have been built on and merged into GDTF. Meyers-Briggs Test Indicator (MBTI) is used for identifying a personal profile. MBTI not only provides numerical scores through quantitative representation scheme, but this also allows plausible linking with the modified Kogut and Singh index (KS index) using the GLOBE dataset.

Psychological cohesiveness and cultural similarity are the main guidelines of the GDTF computational method. The goal is promoting creativity from effective teaming even within globally distributed, culturally diverse design teams. To do so, psychological organization is implemented for promoting creativity. In addition, Psychological Relationship Characteristic (PRC) is utilized to increase psychological harmony with a cognitive functional leader and among team members. Lastly, the modified KS and trust index using GLOBE are developed for measuring cultural similarity.

Although GDTF provides contributions on effective teaming, certain limitations of this study should be noted. Like all typological frameworks which face an issue of generalization error, MBTI and GLOBE cannot be free from this skepticism. However, this research is based on the assumption that MBTI and GLOBE truly reflect people′s psychological modes and countries′ socio-cultural characteristics respectively.

This methodology provides in-depth analysis of a leading psychological team formation theory and proposes a new approach on how to create an effective team using psychological and socio-cultural aspects to overcome the challenges that psychologically and culturally diverse teams face. This method, thereby, leads to establish a theoretical foundation that can be implemented for any type of cross-functional and cultural effective teams and organizations.

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Appendix B

List of participants the response from Teamology questionnaire for MBTI and nationality

Team (2013)		MBTI								School	GLOBE
		e	i	j	p	s	n	t	f		Country
Team 1 Chevrolet	a5	3	2	4	1	3	2	4	1	SJTU	26
	a53	4	1	4	1	2	3	4	1	SJTU	26
	a9	3	2	3	2	4	1	2	3	TUD	58
	a4	4	1	4	1	5	0	3	2	TUD	58
	a15	2	3	2	3	2	3	1	4	MTY	13
	a34 (I.D.)	3	2	4	1	3	2	4	1	MTY	13
	a32	0	5	4	1	4	1	3	2	VT	62
	a13	0	5	4	1	4	1	3	2	VT	62
	a18	5	0	2	3	2	3	1	3	TUD	26
	a46	1	4	3	2	4	1	3	2	TUD	26
Team 2 Buick	a29	0	5	5	0	0	5	5	0	VT	62
	a54	5	0	3	2	5	1	4	1	VT	62
	a19	3	2	1	4	4	1	3	2	MTY	13
	a1	5	0	2	3	4	1	2	3	MTY	13
	a43	3	2	3	2	5	0	4	1	HU	62
	a44	2	3	5	3	4	2	3	2	HU	62
	a7	1	4	5	0	5	0	4	1	TUD	26
	a35	3	2	4	1	4	1	2	3	TUD	26
	a16	3	2	4	0	4	1	4	1	SJTU	26
	a51	4	1	4	1	2	3	4	1	SJTU	26
Team 3 Opel	a45	4	1	2	3	4	1	5	2	TUD	58
	a31	4	1	2	4	5	0	5	0	TUD	58
	a41	5	0	4	1	4	1	3	2	TUD	62

	a25	4	1	2	3	3	2	5	0	VT	62
	a23	2	3	5	0	3	2	4	1	VT	26
	a8	1	4	5	0	0	5	2	3	SJTU	26
	a20	5	0	2	3	4	1	4	1	SJTU	13
	a30 (I.D.)	2	3	4	1	3	1	4	1	MTY	13
	a47	2	4	2	4	5	0	3	2	MTY	26
	a40	2	4	1	4	4	1	3	2	HU	26
Team 4 Daewoo Patac	**a37**	2	3	3	1	0	5	3	2	SJTU	26
	a50	1	4	2	3	5	0	3	2	VT	26
	a27	3	2	4	1	5	0	3	2	TUD	58
	a26	4	2	5	2	2	4	4	2	TUD	58
	a17	2	3	3	2	5	0	1	4	MTY	13
	a58 (I.D.)	4	0	3	2	4	1	5	2	MTY	13
	a38	1	4	2	3	4	1	3	2	VT	62
	a42	5	0	4	1	3	2	3	2	VT	62
	a49	3	2	3	2	3	2	4	1	SJTU	26
	a12	1	4	4	1	4	1	3	2	SJTU	26

***Forty one senior and graduate students from SJTU, TUD, MTY, and VT, are split into four teams consisting of 10-11 students. Under IRB approval (see Appendix A-IRB), MBTI information was collected from Teamology questionnaire with coded name. Additionally, nationality was gathered from GLOBE dataset (see more detail in Appendix B).**

Appendix C

The list of nationality information with nine-dimension from GLOBE dataset

Country	**Number**	4	13	26	58	62
	Name	**India**	**Mexico**	**China**	**Germany**	**USA**
Nine Dimensions from GLOBE	**uncsa**	4.15	4.18	4.94	5.22	4.15
	futsa	4.19	3.87	3.75	4.27	4.15
	powsa	5.47	5.22	5.04	5.25	4.88
	indsa	4.38	4.06	4.77	3.79	4.20
	humsa	4.57	3.98	4.36	3.18	4.17
	achsa	4.25	4.10	4.45	4.25	4.49
	Trisa	5.92	5.71	5.80	4.02	4.25
	malsa	2.90	3.64	3.05	3.10	3.34
	aggsa	3.73	4.45	3.76	4.55	4.55

*** GLOBE nine dimensions: Power distance, Collectivism I, Collectivism II, Assertiveness, Gender Egalitarianism, Uncertainty avoidance, Future Orientation, Performance Orientation, Humane Orientation**

Chapter 5

(Manuscript #2) Framework for effective teaming methodology for global collaborative and creative design teams

Abstract

This paper presents a framework for effective teaming methodology for global collaborative and creative design teams. As an overall framework, a team leader will be selected by the Extended Fuzzy Analytic Hierarchy Procedure (EFAHP), which is multi criteria decision making method. Then people who are psychologically and socio-culturally well matched to the leader and other members will be chosen as team members. To do this, a unification mechanism which is linked-up between psychology and socio-cultural theories is newly proposed and implemented for effective team formation methods. The research objective is to show how a prototype software program using MATLAB-GUI was developed to effectively employ this new framework.

Keywords: Design Creativity and Innovation, Global Collaboration, Team Formation

5.1 Introduction

A creative and innovative product design team is crucial for success in a harsh global economic environment. The burgeoning globalization demands a high performing team composed of globally distributed, culturally diverse members. A cross-functional team based working pattern, which can leverage diverse skills and perspectives from various departments, has become more utilized in firms

(Chen, 2005; Hackman, 2002; McDonough III, Kahnb, & Barczaka, 2001). The team composition considerably influences organizational performance (Chi & Chen, 2009; Wi, Oh, Mun, & Jung, 2009).

Although the real value of a cross-functional team is mainly generated by identifying, leveraging and organizing colleagues′ cognitive abilities, meta-studies (Griffin, 1997; Gupta & Wilemon, 1990) testifying its worth in business areas show that cross-functional teams frequently confront poor team performance (Ancona & Caldwell, 1992; Clark & Wheelwright, 1992). Besides, certain circumstances, such as expanding in team size and involving members from different cultural backgrounds, often deteriorate team effectiveness (Wilde, 2008). As a result, incompatible team members can cause organizational malaise, which leads to high labor turnover and human capital loss (Kiriazov, Sullivan, & Tu, 2000).

To address these issues properly, diverse research on effective team formation has been conducted, thereby facilitating expert systems or decision support systems (Chien & Chen, 2008; Storey Hooper, Galvin, Kilmer, & Liebowitz, 1998), fundamental understandings of multi-disciplinary work and high interdependency task patterns in cross-functional teams (Borman, Hanson, & Hedge, 1997; Robertson & Smith, 2001).

Despite these remarkable contributions, an integrated systematic approach, rather than psychological and socio-cultural respective approach, is imperative, and an expert system or decision support system is still needed. To do so, correlation between psychologically and culturally diverse teams and design creativity has been addressed. Furthermore, addressing these issues, a computational method followed by prototype software has been developed.

5.2 Backgrounds of Global and Design Team Formation

Previous studies have been conducted to determine a proper approach to creating effective global collaborative and creative design teams. The socio-cultural and psychological perspectives on team formation methods discovered in these studies are introduced in this section.

Research on how psychological perspective can enhance creativity has been rigorously conducted in various areas (Glick, Miller, & Huber, 1993; Kilduff, Angelmar, & Mehra, 2000; Miller, Burke, & Glick, 1998; Williams & O'Reilly, 1998). Especially, Wilde has successfully demonstrated that psychological organization had positive correlation with design creativity through more than decades of experiments (Wilde, 2008). This team formation method has not been tested in the creation of a global engineering design team yet, however.

On the other hand, socio-cultural perspective on global team composition has also been examined by many scholars (Dafoulas & Macaulay, 2002; Jung & Sosik, 2002; Kirkman, Rosen, Tesluk, & Gibson, 2004). In addition, the influence of cultural index on teams is tested with simulated experimental conditions among different cultures (Gibson, 1999; Kirkman & Shapiro, 2001). Among several studies, the GLOBE (Global Leadership and Organizational Effectiveness) is the most recent and extensive research of cultural framework and provides a roadmap for international business success (House, Javidan, Hanges, & Dorfman, 2002)

Another approach towards team composition methods, expert systems, which captures human knowledge required for a project, has been receiving attention from scholars (Laudon, Laudon, & Brabston, 2006). Then expert systems with fuzzy logics, genetic algorithms, and neural networks have contributed to effective team composition (Al-Tabtabai, 1998; Liang & Gao, 1999; Storey Hooper et al., 1998).

In order to satisfy multi-disciplinary conditions for global collaborative and creative design teams, integrated systematic solutions, rather than focusing one dominant area, are needed. The newly proposed framework, with the common denominator that links up the different theories, is presented in the following chapters.

5.3 A Framework for Effective Teaming Methodology for Global Collaborative and Creative Design Teams

Related theories have been built to lead to success in global collaboration and design creativity. As a main guideline of socio-cultural framework, GLOBE is implemented. For enhancing design creativity, psychological organization, as successfully demonstrated by Wilde (2008), is implemented. Additionally, a Myers Briggs Type Indicator is used to identify personality.

Distinctly different theories can be plausibly linked by the following key factors. First, the fact that psychological preference type (MBTI) is appropriate and applicable for use by any people in the world (Kirby, Kendall, & Barger, 2007; Schaubhut, Herk, & Thompson, 2009), allows plausible linking between psychology and sociocultural theory, called unification algorithm.

Psychological relationship characteristics can be transformed into quantitative values. The mathematical formulation, whereby linking quantitative values of psychological relationships and cultural similarity, can be established. These key factors allow team composition that simultaneously satisfies creativity as well as psychological cohesiveness.

Therefore, psychological type can be the common denominator linking to sociocultural theory and be an effective solution for globally distributed and culturally diverse cross-functional team formation methodology.

The overall framework for team formation is that qualified leaders will be selected by the Extended Fuzzy Analytic Hierarchy Procedure (EFAHP), which a multi-criteria decision making method. Then, team members must present all eight cognitive modes to derive the most effective results, and members who are psychologically and socio-culturally well matched to the leader and other members will constitute the final team.

5.3.1 Leader Selection

Many studies have shown how important the role of leader is in a global collaboration success (Griffith, Sawyer, & Neale, 2003; Hackman, 2002; House et al., 2002; Jarvenpaa & Leidner, 1998; Kanawattanachai & Yoo, 2007) and human resource management (HRM) (Fabi & Pettersen, 1992; Hinds & Kiesler, 2002; Huemann, Keegan, & Turner, 2007; Tsai, Moskowitz, & Lee, 2003). Furthermore, effective collaboration between team members and team leaders is also crucial to achieve high performance. Therefore, team leader, as well as sub-team members, selection is the crucial element leading to success in an engineering design team.

5.3.1.1 Extended Fuzzy AHP (Analytical Hierarchy Procedure)

Extended Fuzzy Analytical Hierarchy Procedure (EFAHP) developed by Chang (1996) is utilized to select competitive leaders in this study due to the relative benefit in computational efficiency and ease of use. According to Chan and Kumar (2007), Van Laarhoven and Pedrycz (1983) and Buckley (1985) have dealt with AHP′s subjectivity of the pairwise comparison using fuzzy. Nonetheless, their methods cause unreliable results due to their ranking methods and tremendous computations for even simple problems (Bortolan & Degani, 1985).

Consider two triangular fuzzy numbers $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$,

$$M_1 \oplus M_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2)$$

$$\boldsymbol{M_1 \otimes M_2 = (l_1 l_2, m_1 m_2, u_1 u_2)} \qquad \text{Eq. 5-1}$$

$$M_1^{-1} \approx (1/l_1, 1/m_1, 1/l_1)$$

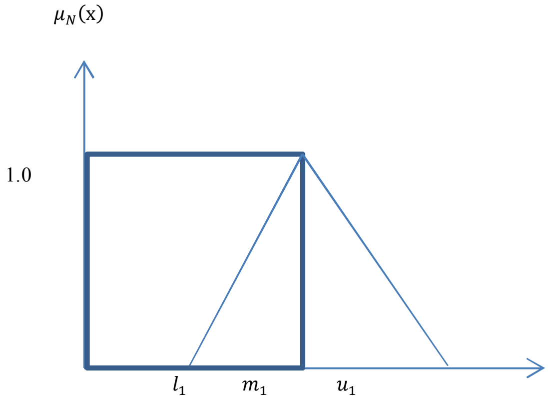

Figure 5-1 A Triangular Fuzzy Number (TFN)

$$\boldsymbol{\mu_N(x)} = \begin{cases} \dfrac{\boldsymbol{x - l_1}}{\boldsymbol{m_1 - l_1}}, & \mathbf{x} \in [\boldsymbol{l_1, m_1}] \\ \dfrac{\boldsymbol{u_1 - x}}{\boldsymbol{u_1 - m_1}}, & \mathbf{x} \in [\boldsymbol{m_1, u_1}] \\ \mathbf{0}, & \boldsymbol{otherwise} \end{cases} \qquad \text{Eq. 5-2}$$

$\boldsymbol{N^1_{Oi}, N^2_{Oi}, \ldots, N^m_{Oi}}$, **where** $\mathbf{i = 1, 2, \ldots, n}$,

where all the N^j_{Oi} $(j = 1,2, \ldots, m)$ are triangular fuzzy numbers.

The value of fuzzy synthetic extent with respect to the ith object is defined as

$$F_i = \sum_{j=1}^{m} N^j_{Oi} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} N^j_{Oi}\right]^{-1} \qquad \text{Eq. 5-3}$$

Where,

$$\sum_{j=1}^{m} N^j_{Oi} = \left\{\sum_{j=1}^{m} l_{1j}, \sum_{j=1}^{m} m_{2j}, \sum_{j=1}^{m} u_{3j}\right\} \qquad \text{Eq. 5-4}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} N^j_{Oi} = \left\{\sum_{j=1}^{n} l_{j1}, \sum_{j=1}^{n} m_{j2}, \sum_{j=1}^{n} u_{j3}\right\} \qquad \text{Eq. 5-5}$$

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} N^j_{Oi}\right]^{-1} = \left\{\frac{1}{\sum_{i=1}^{n} l_{i3}}, \frac{1}{\sum_{i=1}^{n} m_{i2}}, \frac{1}{\sum_{i=1}^{n} u_{i1}}\right\} \qquad \text{Eq. 5-6}$$

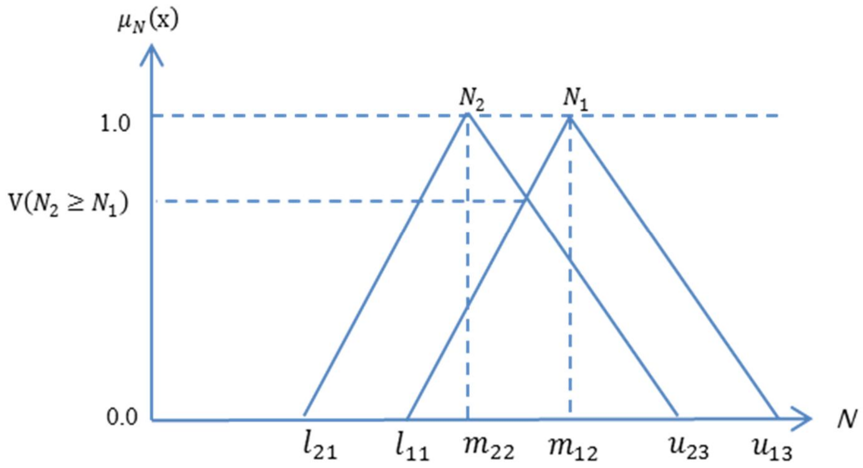

Figure 5-2 The membership function of the triangular fuzzy numbers (TFN)

The degree of possibility of $N_1 = (l_{11,}m_{12,}u_{13}) \geq N_2 = (l_{21,}m_{22,}u_{23})$ is defined as

$$\mathrm{V}(N_1 \geq N_2) = \sup_{x \geq y}[\min(\mu_{N1}(x), \mu_{N2}(y))]$$

$$\mathrm{V}(N_1 \geq N_2) = 1 \qquad\qquad if \quad m_{11} \geq m_{22}$$

Eq. 5-7

$$\mathrm{V}(N_2 \geq N_1) = \begin{cases} 0 & if \quad l_{12} \geq u_{23} \\ hgt(N_1 \cap N_2) = \mu_{N1}(\mathrm{d}) = \dfrac{l_{11} - u_{23}}{(m_{22} - u_{23})(m_{12} - l_{11})} \end{cases}$$

In order to compare N_1 *and* N_2 , both $\mathrm{V}(N_1 \geq N_2)$ and $\mathrm{V}(N_2 \geq N_1)$ are necessary. The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers $N_i (i = 1,2, \ldots, k)$ can be defined by

$$\mathrm{V}(N \geq N_1, N_2, \ldots, N_k)$$

$$= \boldsymbol{V}[(\boldsymbol{N} \geq \boldsymbol{N_1}) \; \boldsymbol{and} \ldots \boldsymbol{and} \; (\boldsymbol{N} \geq \boldsymbol{N_k})] \qquad \text{Eq. 5-8}$$

$$= min \; V(N \geq N_i)$$

$$\text{if } \; m(p_i) = \min V\,((F_1 \geq F_k),$$

for k=1, 2, n; k≠ i , then the weight factor is given by$W_p = ((m(P_1), m(P_2), \ldots, m(P_n))^T$, where P_i , i=1,2,..., n

After normalizing W_p, we get the normalized weight vectors

$$\boldsymbol{W_n} = \left(\boldsymbol{w}(\boldsymbol{P_1}), \boldsymbol{w}(\boldsymbol{P_2}), \dots, \boldsymbol{w}(\boldsymbol{P_n})\right)^{\boldsymbol{T}} \quad \text{Eq. 5-9}$$

$$\sum_{i=1}^{n} \boldsymbol{w}(\boldsymbol{P_i}) = \mathbf{1} \quad \text{Eq. 5-10}$$

Table 5.1 Triangular fuzzy conversion scale

Linguistic Scale	Triangular Fuzzy Function	Triangular Fuzzy Reciprocal Function
Just_Equal	[1,1,1]	[1,1,1]
Equally_Important	[1/2,1,3/2]	[2/3,1,2]
Weakly_Important	[1,3/2,2]	[1/2,2/3,1]
Strongly_Important	[3/2,2,5/2]	[2/5,1/2,2/3]
Very_Strongly_Important	[2,5/2,3]	[1/3,2/5,1/2]
Absolutely_Important	[5/2,3,7/2]	[2/7,1/3,2/5]

The triangular fuzzy conversion scale shown in Table 5.1 is defined for the EFAHP evaluation matrix.

5.3.1.2 An Illustrative Example of EFAHP

Under the National Science Foundation (NSF) funding, Virginia Tech (US) and the Technische Universität Darmstadt (Germany) have founded the Research Experiences for Undergraduates (REU) in Automotive Technologies program. The objective of this program is to encourage students to pursue a graduate degree and to provide a unique experience for a research career within an international context in automotive technology areas. In addition, this program also seeks solutions for successful transatlantic research collaborations by effective teaming between transatlantic faculty and students collaborations.

In order to achieve these goals successfully, hiring the best fitting students to meet our program criteria is essential. In the 2013 summer program, there are three candidates who met requirements for this program. In this study, the Extended Fussy Analytic Hierarchy Procedure (EFAHP) is implemented to find the person who is the best fit among the alternatives.

As a first step, hierarchy structure with criteria and alternatives can be established (Figure 5. 3). Three main criteria, which are academic performance (C1), skill set (C2), and experience (C3), are considered.

Alternatives of academic performance are consisted of overall GPA (A1), major elective course GPA (A2), Math (A3), and Recommendation (A4). In skill set, hardware (A5) and software skills (A6) are included. Experience is composed of class projects (A7), research (A8), project leadership (A9), and travel (A10).

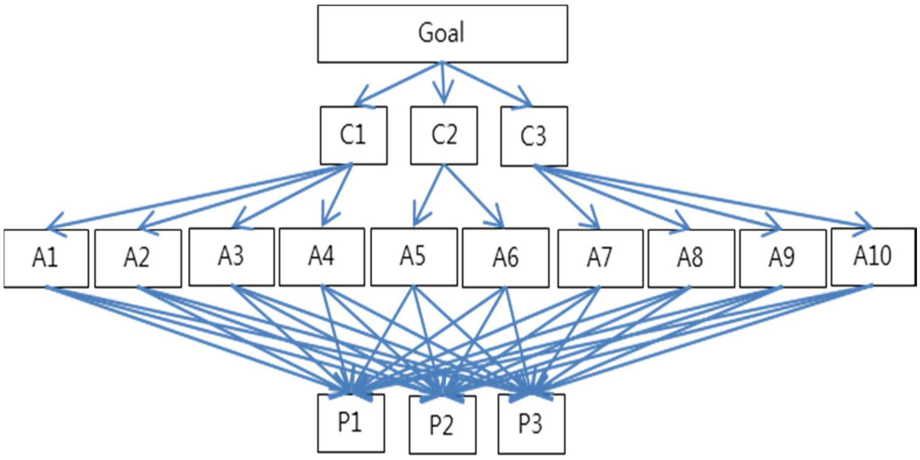

Figure 5-3 The Hierarchy structure

Once the multi criteria decision making problem is modeled by the hierarchy structure, the pairwise comparison matrix can be established like the following:

Table 5.2 The fuzzy evaluation matrix with respect to the goal

	Academic Performance (C1)	Skill (C2)	Experience (C3)
Academic Performance (C1)	[1,1,1]	[1/2,1,3/2]	[3/2,2,5/2]
Skill (C2)	[2/3,1,2]	[1,1,1]	[1,3/2,2]
Experience (C3)	[2/5,1/2,2/3]	[1/2,2/3,1]	[1,1,1]

Table 5.3 Evaluation of alternatives with respect to Academic Performance

	Overall GPA (A1)	Major Elective Course GPA (A2)	Math (A3)	Recommendation (A4)
Overall GPA (A1)	[1,1,1]	[2/5,1/2,2/3]	[2/5,1/2,2/3]	[1/2,1,3/2]
Major Elective Course GPA (A2)	[3/2,2,5/2]	[1,1,1]	[2/5,1/2,2/3]	[2,5/2,3]
Math (A3)	[3/2,2,5/2]	[3/2,2,5/2]	[1,1,1]	[2,5/2,3]
Recommendation (A4)	[2/3,1,2]	[1/3,2/5,1/2]	[1/3,2/5,1/2]	[1,1,1]

Table 5.4 Evaluation of alternatives with respect to skill set

	Hardware Skill (A5)	Software Skill (A6)
Hardware Skill (A5)	[1,1,1]	[1/3,2/5,1/2]
Software Skill (A6)	[2,5/2,3]	[1,1,1]

Table 5.5 Evaluation of alternatives with respect to experience

	Class Project (A7)	Research (A8)	Project Leader (A9)	Travel (A10)
Class Project (A7)	[1,1,1]	[2/5,1/2,2/3]	[2/5,1/2,2/3]	[3/2,2,5/2]

Research (A8)	[3/2,2,5/2]	[1,1,1]	[2/5,1/2,2/3]	[3/2,2,5/2]
Project Leader (A9)	[3/2,2,5/2]	[3/2,2,5/2]	[1,1,1]	[5/2,3,7/2]
Travel (A10)	[2/5,1/2,2/3]	[2/5,1/2,2/3]	[2/7,1/3,2/5]	[1,1,1]

Table 5.6 Evaluation of candidates with respect to alternatives

	Overall GPA (A1)			Major Elective Course GPA (A2)			Math / Pysics/ Chemistry (A3)			Recommendation (A4)			Hardware Skill (A5)		
	Student (S1)	Student (S2)	Student (S3)	Student (S1)	Student (S2)	Student (S3)	Student (S1)	Student (S2)	Student (S3)	Student (S1)	Student (S2)	Student (S3)	Student (S1)	Student (S2)	Student (S3)
Student (S1)	[1,1,1]	[3/2,2,5/2]	[2,5/2,3]	[1,1,1]	[3/2,2,5/2]	[2,5/2,3]	[1,1,1]	[3/2,2,5/2]	[2,5/2,3]	[1,1,1]	[2/3,1,2]	[3/2,2,5/2]	[1,1,1]	[1/2,1,3/2]	[3/2,2,5/2]
Student (S2)	[2/5,1/2,2/3]	[1,1,1]	[2/3,1,2]	[2/5,1/2,2/3]	[1,1,1]	[3/2,2,5/2]	[2/5,1/2,2/3]	[1,1,1]	[3/2,2,5/2]	[1/2,1,3/2]	[1,1,1]	[2,5/2,3]	[2/3,1,2]	[1,1,1]	[3/2,2,5/2]
Student (S3)	[1/3,2/5,1/2]	[1/2,1,3/2]	[1,1,1]	[1/3,2/5,1/2]	[2/5,1/2,2/3]	[1,1,1]	[1/3,2/5,1/2]	[2/5,1/2,2/3]	[1,1,1]	[2/5,1/2,2/3]	[1/3,2/5,1/2]	[1,1,1]	[2/5,1/2,2/3]	[2/5,1/2,2/3]	[1,1,1]

	Software Skill (A6)			Class Project (A7)			Research (A8)			Project Leader (A9)			Travel (A10)		
	Student (S1)	Student (S2)	Student (S3)	Student (S1)	Student (S2)	Student (S3)	Student (S1)	Student (S2)	Student (S3)	Student (S1)	Student (S2)	Student (S3)	Student (S1)	Student (S2)	Student (S3)
Student (S1)	[1,1,1]	[3/2,2,5/2]	[2/5,1/2,2/3]	[1,1,1]	[1/2,1,3/2]	[3/2,2,5/2]	[1,1,1]	[1/2,1,3/2]	[3/2,2,5/2]	[1,1,1]	[2/5,1/2,2/3]	[3/2,2,5/2]	[1,1,1]	[2/5,1/2,2/3]	[3/2,2,5/2]
Student (S2)	[2/5,1/2,2/3]	[1,1,1]	[2/7,1/3,2/5]	[2/3,1,2]	[1,1,1]	[3/2,2,5/2]	[2/3,1,2]	[1,1,1]	[3/2,2,5/2]	[3/2,2,5/2]	[1,1,1]	[5/2,3,7/2]	[3/2,2,5/2]	[1,1,1]	[3/2,2,5/2]
Student (S3)	[3/2,2,5/2]	[5/2,3,7/2]	[1,1,1]	[2/5,1/2,2/3]	[2/5,1/2,2/3]	[1,1,1]	[2/5,1/2,2/3]	[2/5,1/2,2/3]	[1,1,1]	[2/5,1/2,2/3]	[2/7,1/3,2/5]	[1,1,1]	[2/5,1/2,2/3]	[2/5,1/2,2/3]	[1,1,1]

EFAHP software program has been developed by MATLAB-2011b and validated through Büyüközkan, Kahraman, and Ruan (2004). All evaluation matrixes shown in Tables 5.2 to 5.6 have gone through the program. Table 5.7 presents the summary of results from EFAHP. The results show that candidate number one gets the highest priority.

Table 5.7 Summary of priority weights with respect to criteria

	Academic Performance				
	Overall GPA	Major Elective Course GPA	Math/Physics/Chemistry	Recommendation	Alternative Priority Weight
Student 1	0.77	0.73	0.73	0.47	0.73
Student 2	0.19	0.27	0.27	0.53	0.27
Student 3	0.04	0.00	0.00	0.00	0.00

	Skill		
	Hardware Skill	Software Skill	Alternative Priority Weight
Student 1	0.46	0.17	0.17
Student 2	0.46	0.00	0.00
Student 3	0.09	0.83	0.83

	Experience				
	Class Project	Research	Project Leader	Travel	Alternative Priority Weight
Student 1	0.41	0.46	0.17	0.34	0.28
Student 2	0.33	0.46	0.83	0.66	0.68
Student 3	0.26	0.09	0.00	0.00	0.04

	Academic Performance 0.44	Skill 0.39	Experience 0.17	Alternative Priority Weight
Student 1	0.73	0.17	0.28	0.43
Student 2	0.27	0.00	0.68	0.23
Student 3	0.00	0.83	0.04	0.33

5.3.1.3 Psychologically and Socio-culturally well matched Team Members

Once the leader has been selected by Extended Fuzzy Analytical Hierarchy Procedure (EFAHP), team members can be nominated from people who are psychologically and socio-culturally well matched to the leader and other team members. To do so, a psychological and socio-cultural team formation formulation has been developed through quantitative representation schemes.

The formulation consists of three terms, which are trust index, cultural similarity, and psychological relationship characteristics. Trust index is rooted in the difference between social practice (most often observed behavior) and value (desired social behavior) which are defined in the GLOBE (*<u>G</u>lobal <u>L</u>eadership and <u>O</u>rganizational <u>E</u>ffectiveness)* data. Cultural similarity is originated from the inverse of Kogut and Singhs′ cultural difference index. The last term, PRC, represents psychological relationships between bipolar types with respect to the leader.

$$\underset{\text{personal value w.r.t. each cognitive leader}}{\underline{GDTF}} = MAX \frac{\left[\sum_{i=1}^{n} \omega_{c,j}\omega_{c,l}\right] * \left[\sum_{i=1}^{n}\{1-\left(I_{i,j}-I_{i,l}\right)^{2}/(V_i *\right.}{\sum_{k=1}^{m}\left[\frac{m\,!}{2!\,(m-2)!}\right]} \qquad \text{Eq. 5-11}$$

Where:

CP_{ij}: Social Practice Values of the ith cultural dimension andd jth (sub-team) from GLOBE data set
CV_{ij}: Social Values of the ith cultural dimension andd jth (sub-team) from GLOBE data set
I_{ij}: Index for the ith cultural dimension and j th country
I_{il}: Index for the ith cultural dimension and leaders
V_i: Variance of the index of the ith cultural dimension
n: Number of Cultural Dimensions (CD)
Wci Wcl: personal relationship characteristic factors between ith sub-team from c cognitive functional mode and l th(leader) from c cognitive functional mode

$$\underset{\text{team value}}{\underline{GDTF}} = MAX \sum_{k=1}^{m-1}\sum_{j=1}^{m-k}\sum_{i=1}^{n} \frac{\left[\{1-\left(I_{i,j+k}-I_{i,j+k-1}\right)^{2}/(V_i * n)\} * \omega_{c,j+k}\omega_{c,j+k-1}\right]}{\left[\frac{m\,!}{r!\,(m-r)!}\right]} \qquad \text{Eq. 5-12}$$

where:

$CP_{i,j+k}$: Social Practice Values of the ith cultural dimension and j+k th (sub-team) from GLOBE data set
$CV_{i,j+k}$: Social Values of the ith cultural dimension and j+k th (sub-team) from GLOBE data set
$I_{i,j+k}$: Index for the ith cultural dimension and j+k th member's country
$I_{i,j}$: Index for the ith cultural dimension and j th member's country
V_i: Variance of the index of the ith cultural dimension
n=9: Number of Cultural Dimensions (CD)
r=relationship, e.g. r=2 default
m: Number of sub-team members
Wc,j+k Wc,j+k-1: personal relationship characteristic factors between j+k th (sub-team) from c cognitive functional mode and j+k-1 th (sub-team) from c cognitive functional mode

The first formula checks psychological and socio-cultural matching to the leader. Once a pool of team members is made from the first equation, final team members can be determined by the second formula.

5.3.2 Prototype Software Program Development

The goal of the prototype software development through the MATLAB Graphical User Interface (MATLAB -GUI) is in simplifying detail procedures and visualizing core results. This program thereby contributes to a user-friendly solution, effective application, and capability to handle large amounts of data.

5.3.2.1 Visualization by MATLAB- Graphic User Interface (GUI)

Global Teamology GUI is composed of activation and cultural effect optional buttons and a result display portion, as shown in Figure 5.4. In the area of the activation and cultural effect optional buttons, the user can put a desired team number. Then the result shows only limited numbers of highly ranked members. The cultural effect option button exists for the case of participants coming from different cultural backgrounds. For instance, if all participants have the same cultural background, then the team composition result only depends on Psychological Relationship Characteristics (PRC). In case of globally distributed and culturally diverse teams, the cultural effect option has to be chosen for utilizing GLOBE data and formulation for the optimum results.

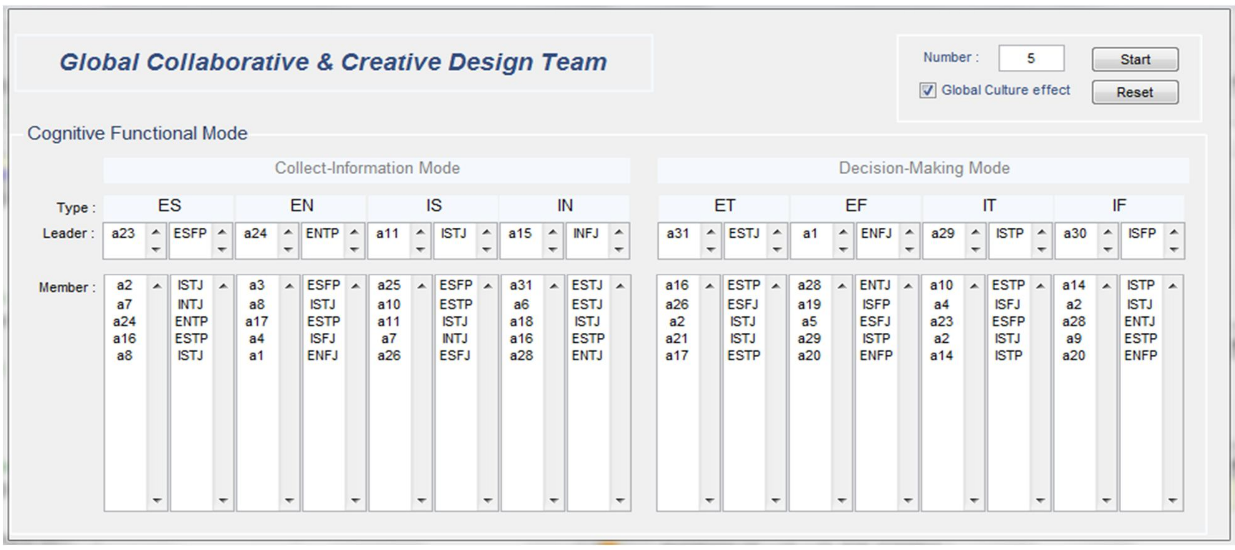

Figure 5-4 GUI Template for Global Teamology

The last part of GUI shows the result of team formation. The top layer provides team leaders, chosen through the EFAHP method, of eight different cognitive types and their coded names. Eight cognitive types, which are ES, EN, IS, IN, ET, EF, IT, IF, are arranged from the left to the right. Under each cognitive leader, members' coded names with their cognitive type are listed below.

5.3.2.2 Flow Chart and Detail Procedure

The flow chart (Figure 5.5) and detail procedures for sub-team resource selection and allocation are the following: first, calculating MBTI is conducted by the question response from all participants. Once a database for MBTI is obtained, collection and decision-making modes are categorized by any combination of attitudes (Extraversion (E) or Introversion (I)) and life style (Judging (J) or Perceiving (P)). According to the Briggs attitude, someone who concurrently has either E and P or I and J is categorized by a collect-information mode. On the contrary, someone who simultaneously contains either E and J or I and P is classified by decision-making mode. Within each pool of personal type, sub-team members, who qualify all conditions, are selected by implementing developed formulas.

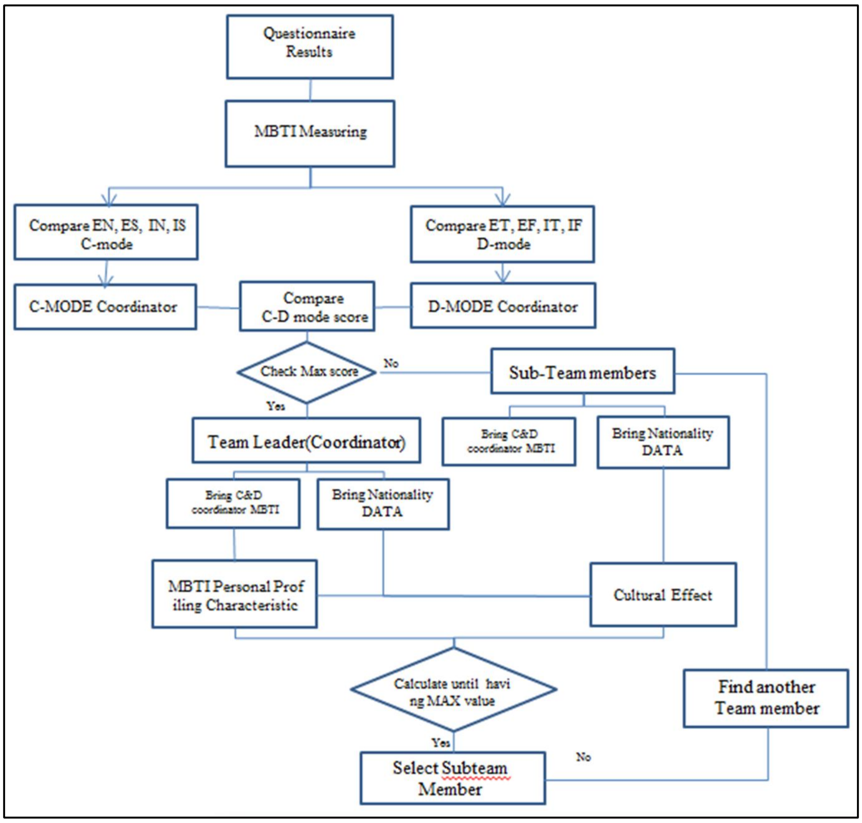

Figure 5-5 Flow Chart

5.4 Conclusion

This paper presented a framework and developed software for a creating a global collaborative and creative design team. To do so, psychological, and socio-cultural theories have been built upon and merged, creating the unification mechanism. Extended Fuzzy Analytical Hierarchy Procedure (EFAHP), which is reasonable decision-making, has been implemented for the leader selection. Newly developed formulas based on quantitative representation schemes have also been utilized for compatible team member selection.

As the main guideline, the unification mechanism, how the human's psychological characteristic is universally applicable to team formation anywhere in globe, makes it possible to integrate two different areas. Psychological cohesiveness and cultural similarity among globally distributed members also provides a plausible solution for conflict management (CM).

As last part of solution, prototype software development for visualization and computational efficiency shows its feasibility in other types of computational language.

Not only did the proposed team formation methodology fulfill the demands of a multi-disciplinary and multi-cultural working patterns, it also provides new theoretical foundation of global collaborative and creative design team formation.

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Appendix D

Extended Fuzzy Analytical Hierarchy Procedure (EFAHP)

Name	Value	Min	Max
Absolutely_Important	[2.5000,3,3.5000]	2.5000	3.5000
Equally_Important	[0.5000,1,1.5000]	0.5000	1.5000
Final_ranking	[0.4337;0.2331;0.3332]	0.2331	0.4337
Just_Equal	[1,1,1]	1	1
Reciprocal_Absolutely_Important	[0.2857,0.3333,0.4000]	0.2857	0.4000
Reciprocal_Equally_Important	[0.6667,1,2]	0.6667	2
Reciprocal_Just_Equal	[1,1,1]	1	1
Reciprocal_Strongly_Important	[0.4000,0.5000,0.6667]	0.4000	0.6667
Reciprocal_Very_Strongly_Impor...	[0.3333,0.4000,0.5000]	0.3333	0.5000
Reciprocal_Weakly_Important	[0.5000,0.6667,1]	0.5000	1
Strongly_Important	[1.5000,2,2.5000]	1.5000	2.5000
Very_Strongly_Important	[2,2.5000,3]	2	3
Weakly_Important	[1,1.5000,2]	1	2
alternative_priority1	[0.7281;0.2719;0]	0	0.7281
alternative_priority2	[0.1700;0;0.8300]	0	0.8300
alternative_priority3	[0.2771;0.6790;0.0440]	0.0440	0.6790
alternative_priority_matrix	[0.7281,0.1700,0.2771;...	0	0.8300
alternative_priority_weight	[0.4337;0.2331;0.3332]	0.2331	0.4337
alternatives_sub	<10x1 cell>		
cell_combine1	<4x3 double>	0	0.7714
cell_combine2	[0.4572,0.4572,0.0857;...	0	0.8300
cell_combine3	<4x3 double>	0	0.8300
criteria_goal	<1x1 cell>		
i	10	10	10
nomalized_alternative_priority1	[0.7281;0.2719;0]	0	0.7281
nomalized_alternative_priority2	[0.1700;0;0.8300]	0	0.8300
nomalized_alternative_priority3	[0.2771;0.6790;0.0440]	0.0440	0.6790
sub_attributes	<3x1 cell>		
weight_vector1	<1x1 cell>		
weight_vector2	<1x3 cell>		
weight_vector3	<1x10 cell>		

Chapter 6

(Manuscript #3) Effectiveness of Psychologically Diverse and Cohesive Teaming Method and Creativity Index in Mechanical Engineering

Abstract

Design creativity and innovation plays a significant role in business success. For this reason, much research on design creativity has been conducted. Among diverse approaches on design creativity, design metrics and techniques for idea generation (IG) have been mainly studied. On the other hand, effective team forming itself has been highlighted as a crucial factor that achieves design creativity. In this study, psychologically diverse and cohesive teaming method is highlighted and the effectiveness of this method is presented. To do this, forty two mechanical engineering student teams of three at Virginia Polytechnic and State University participated in this experiment. Then, students were asked to generate concepts with general intuitive ideation methods. The generated concepts were evaluated by Innovative Characteristic Metric (ICM). As statistical analysis, Spearman correlation analysis was performed to investigate correlation between new teaming method and product innovation. Furthermore, ordinal logistic regression was conducted to scrutinize what psychological types contribute to product innovation. Statistical results support that psychologically cohesive teams within the context of diversity are positively correlated with innovativeness (Roh: 0.80, $p<0.0001$). Among eight psychological types, Extraverted ("E"), Sensory ("S"), Feeling ("F"), and Judging ("J") are positively correlated with product innovation. Furthermore, Extraverted Intuition ("EN"), Extraverted Thinking ("ET"), Extraverted Feeling

("EF"), and Introverted Feeling ("IF") are significantly correlated to product innovation. Based on findings, Creativity Index (CI) using psychological types for mechanical engineering teams is experimentally determined to predict team performance.

Keyword: Psychological Teaming, Design Creativity, Innovation Metric

6.1 Introduction

Design creativity and product innovation directly contribute to economic growth thereby increasing sales and revenue. For this reason, scholars have put their efforts to identify characteristics of creativity and devise a novel method to promote design creativity and product innovation. Among several approaches, sites of research can be thought of as two different groups: One is to develop Idea Generation (IG) metrics, which allow the generation of original and innovative concepts. The other one focuses on developing a group based working pattern.

Since Idea Generation (IG) techniques were studied, diverse techniques have been developed and applied to design projects (Linsey, 2007). Within various techniques of Idea Generation, progressive technique such as 6-3-5 (Shah, 1998), C-sketch (Shah, Kulkarni, & Vargas-Hernandez, 2000), and hybrid types (6-3-5/C-sketch)(Shah, VARGAS-HERNANDEZ, Summers, & Kulkarni, 2001) have predominantly used in college level projects (Shah, Smith, & Vargas-Hernandez, 2003). Nonetheless, there are no certain techniques and metrics which are most appropriate to use.

Aside from developing IG metrics, forming effective teams that follow all design process faithfully has emerged as an important factor affecting design outcomes (Finke, Ward, & Smith, 1992; D. Jensen, Feland, Bowe, & Self, 2000). Since then, many scholars have developed different techniques and that have been applied for forming effective teams (D. Jensen et al., 2000; Wilde, 2008). Among those techniques, many scholars have successfully demonstrated that psychological teaming techniques lead to creative design thinking and product innovation (McCaulley, 1990). Yet, skeptical perspectives on employing these methods in global settings have remained an unsolved problem.

Therefore, this paper presents the newly developed method, psychologically diverse and cohesive team composition and examines the effectiveness of this method. Research and evaluation method followed by statistical results are presented.

6.2 Literature reviews

Since psychological profiling methods were developed, many scholars have studied the correlation between creativity and personality traits. Based on comprehensive reviews, sensory(S) versus intuitive(N) category is seen by most researchers to be the most important of the four categories in terms of implications for creativity in education (Borchert, Jensen, & Yates, 1999; Feland & Jensen, 2000; DD Jensen & Bowe, 1999a; D. D. Jensen, Murphy, & Wood, 1998; Myers, McCaulley, & Most, 1985). In the pool of managers and teachers, creative individuals tend to be more introverted ("I") than extroverted ("E"), more intuitive ("N") than sensory ("S"), more thinking ("T") than feeling ("F"), and more perceiving (″P″) rather than judging ("J") (Fleenor & Taylor, 1994; Houtz, LeBlanc, Butera, & Arons, 1994). On the other hand, another research stressed that individuals having ″E″, ″N″, ″T″, and ″P″ were more creative than others (Myers, McCaulley et al. 1985; Gough and Library 1981). However, Bannerot′s long-term study showed that students having ″S″, ″T″, and ″J″ types have a positive correlation with graduation success in University of Houston (Bannerot, 2007). In summary, there are no certain clues indicating E/I are significantly related to creativity, although S/N are highly correlated to creativity.

Table 6.1 Research on Personality Traits

Authors	Personality Traits
DD Jensen and Bowe (1999), Borchert, Jensen, and Yates (1999),D. Jensen et al. (2000)	sensory(S) versus intuitive(N) category
Fleenor and Taylor (1994), Houtz et al. (1994)	introverted("I"), intuitive ("N"), thinking ("T"), and perceiving (″P″)
Myers, McCaulley, and Most (1985), Gough and Library (1981)	extroverted ("E"), intuitive ("N"), thinking ("T"), and perceiving (″P″)
Bannerot (2007)	sensory(″S″), thinking ("T"), and judging (″J″)
Guilford and Hoepfner (1966),	introverted("I") and intuitive ("N")

Durling, Cross, and Johnson (1996), Wang and Cheng (2010), Carr, De La Garza, and Vorster (2002)	intuitive ("N"), and perceiving ("P")

Beyond identifying correlation between cognitive modes and creativity, Wilde developed the method combining Jung's cognitive and Belbin's role theories for creative teams that cover all 8 cognitive functional modes. Wilde has demonstrated a positive correlation between balanced personality diversities and design creativity through more than a decade of experiments (Wilde, 2008). As a team, leaders who have the highest score in each cognitive functional mode are selected. Then, rest members are occupied by the request of regular and marginal members' preference.

On the other hand, the 6-Hats (DeBono, 1985) based team formation strategy utilizes both students' psychological types and communication styles (D. Jensen et al., 2000). Unlike Wilde's method, the Keirsey Temperament Sorter (II) is used to identify students' personalities. Based on students' personal types, 6-Hats is utilized to identify communication preference for critical group decision-making and enhancing leadership in the stage of idea generation and design processing.

Although the details of the two methods are different, they share the fact that personal profiling is the center of these teaming techniques. Therefore, psychological teaming strategies have been applied to team forming to enhance design creativity. Based on Wilde's Teamology, the newly developed team forming method, which is named psychologically cohesive team formation method, is proposed and applied to team forming.

6.3 Psychologically Diverse and Cohesive Team Formation Method

This newly developed method, the Global Design Team Formation (GDTF) method, is an extension of Teamology that merges with the Kogut and Singh index (KS index) using the Global Leadership and Organization Behavior Effectiveness (GLOBE) dataset. Unlike other psychological teaming techniques, GDTF can not only apply to a team having culturally diverse and geographically distributed members, but this can be also used in localized team members who typically focused on design creativity. This method, besides, provide a solution for cohesion and alienation problems in psychological teaming methods.

The main guideline of this new methodology is that a team consisting of psychologically diverse and cohesive members is more likely to produce creative design thinking. Within the context of psychological diversity, a final team roster can be determined by psychological relationship characteristic (PRC), coded by negative, neutral, and positive relationships among different personalities. For instance, a team of three is composed of one cognitive leader and two members who have relatively high scores in PRC and support other cognitive functional areas that the leader did not have.

6.4 Research Method

A research method was established to examine the effectiveness of the GDTF method and identify psychological factors underlying creative design success. To do so, an experiment was designed and conducted in Engineering Design and Economics (ME 2024) in Mechanical engineering at Virginia Polytechnic and State University for three years. Forty two teams, which is a large enough sample size to ensure statistical validity (Hogg, 2006), participated. Student teams were asked to generate product concepts using general intuitive ideation methods for developing certain products. Then the metric evaluating innovativeness and following procedures is discussed in chapter 6.5. Statistical evaluation and correlation analysis is presented in chapter 6.7.

6.5 Concept Evaluation Method

Concepts generated from employing GDTF to student teams can be evaluated by commonly used metrics such as novelty and originality (Shah, Kulkarni, & Vargas-Hernandez, 2000; Shah, Smith, & Vargas-Hernandez, 2003) to measure effectiveness of innovation. Despite the fact that these metrics are well-known, there are drawbacks.

According to Saunders and coauthors′ study on evaluation of innovativeness of those metrics, originality metric has limitations related to subjective measurement and implicit judgment. In addition, the main drawback of the novelty metric is on comparing concepts to others to measure uniqueness within the same ideas generation session rather than comparing to past or current products in the market (Saunders, Seepersad, & Hölttä-Otto, 2011).

With this reason, Innovative Characteristic Metric (ICM), as created by Saunders and coauthors (Saunders et al., 2011), is implemented as the concept evaluation metric in this study. This ICM measures innovativeness of generated ideas by comparison to products benchmarks in current markets. From the in-depth analysis of 197 award-winning products over other competitors, scholars became aware of the fact that characteristic of innovation can be successfully described by five categories.

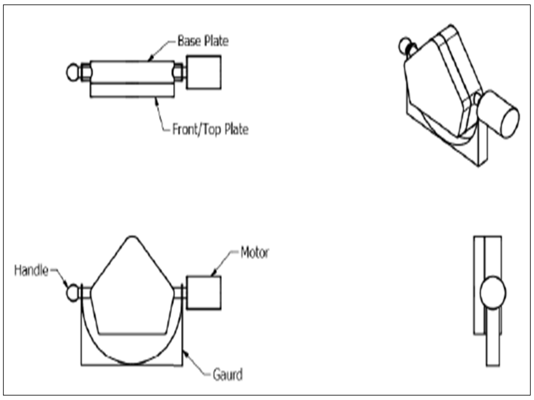
Table 6.2 Innovative Characteristic Metric (ICM) (Saunders et al., 2011)

ICM Categories		Definition
Functionality	**Additional Function**	Allows the user to solve a new problem or perform a new function while still performing the function of the comparison product
Architecture	**Modified Size**	The physical dimensions during operation or storage have changed in expansion or compaction beyond subtle or incremental differences
	Modified Layout	The same elements of the product are still present, but the physical architecture has changed
	Expanded Usage Environment	The product can now be used in more usage environments with different resource availability or different physical characteristics
Environmental Interactions	**Modified Material Flow**	Accepts or creates different materials or uses materials in new ways
	Modified Energy Flow	Utilizes new sources of energy or converts to a different form of energy than previously used
	Modified Information Flow	Different types or amounts of information are being gathered, processed, or output/displayed
	Interaction w/ Infrastructure	The product interacts with previously owned infrastructure
User Interactions	**Modified Physical Demands**	The product is easier to use physically beyond subtle or incremental differences
	Modified Sensory Demands	The product is easier to use from a sensory stand point beyond subtle or incremental differences
	Modified Cognitive Demands	The product is easier to use mentally beyond subtle or incremental differences
Cost	**Purchase Cost**	Purchase cost is significantly different
	Maintenance Cost	Operating and/or maintenance costs are significantly different.

As shown in Table 6.1, five major categories of innovation were identified: functionality, architecture, external interactions, user interactions, and cost. The first category is to check if the final concept offers significant new functions with respect to competitive products. The second category is to evaluate whether new products have any architectural innovations in size, layout, or usage context. The third category, which is external interactions, focuses on modified flows of material, energy, or information as well as interactions with pre-existing infrastructures. The user interactions′ category is to measure how much more the user-friendly final concept meets physical, sensory, and mental demands. The final category is to see how products are significantly different in purchase and maintenance cost from competitive products. Two examples of student products were selected to show how ICM can be applied.

The flip and jack, which is illustrated in Figure 6.1 (a), is an automated flipping device which can be mounted in oven to help better cooking with conventional ovens. This product is controlled remotely by the time that users want. By signal, the motor receives and initiates the rotations of the enclosure.

The automatic fetching player in Figure 6.1 (b) is a device for playing fetch with a dog without any user's help. This device equips the shooter motor, powered by a rechargeable lithium ion battery, to pull and release spring. Various angles, heights and distance can be set by the user and various ball speeds and interval timing are also available.



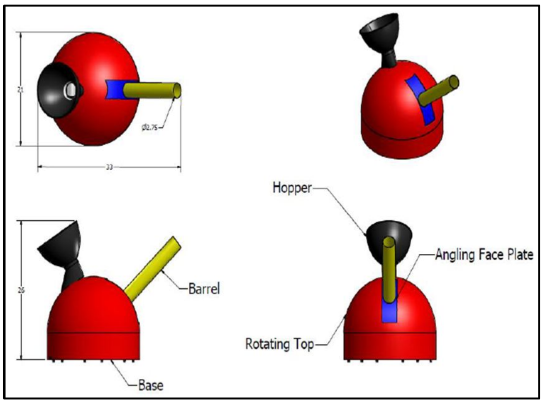


Figure 6-1 (a) The Flip & Jack **Figure 6-2 (b) Automatic fetch machine**

The evaluated products by innovation characteristics are summarized in Table 6.2. Features of both motorized flipping and remote control systems justify a mark in "Additional Function." This product, designed for fit and use in conventional ovens, is qualified for marks in "Modified Physical layout" and "Interaction with Infrastructure." The motor, which physically rotates the device and provides a signal to a remote controller, is credited with "Modified Physical Demands" and "Modified Information Flow." The alarm function, which allows users to know the time flipping over, is recognized by "Modified Sensory Demands."

In the automatic fetch machine, adding rotational function and changing layout for adjustable shooting angle justifies marks "Additional Function" and "Modified Layout." The spring based launching system satisfies "Modified Physical Demands." This product also has competitive price over competing products ("Purchase Cost").

Table 6.3 The result of ICM evaluation

ICM Categories		The Flip & Jack	Automatic fetch machine
Functionality	Additional Function	x	x
Architecture	Modified Size		
	Modified Layout		x
	Expanded Usage Environment	x	
Environmental Interactions	Modified Material Flow		
	Modified Energy Flow		
	Modified Information Flow	x	
	Interaction w/ Infrastructure	x	
User Interactions	Modified Physical Demands	x	x
	Modified Sensory Demands	x	
	Modified Cognitive Demands		
Cost	Purchase Cost	x	x
	Maintenance Cost		

6.6 Inter-rater Reliability

Cronbach's alpha (Cronbach, 1951) for inter-rater reliability was conducted to measure the extent to which three judges' results are consistent in evaluating final products (Gwet, 2001). Generally, acceptable value of Cronbach's alpha for internal consistency is above 0.70 (George, 2003).

Table 6.4 Rule of thumb for describing internal consistency

Cronbach's alpha	Internal consistency
$\alpha \geq 0.9$	Excellent
$0.7 \leq \alpha < 0.9$	Good
$0.6 \leq \alpha < 0.7$	Acceptable
$0.5 \leq \alpha < 0.6$	Poor
$\alpha < 0.5$	Unacceptable

As procedure, three judges trained themselves on ICM by repeated the exercise with randomly selected products. After then, four different final products were given to judges and the three sets of final results were used for internal consistency. Subsequently, Cronbach′s alpha of 0.92 was achieved for the ICM. Therefore, excellent internal consistency was observed in this study.

6.7 Statistical Evaluation

Statistical analysis was performed by JMP 10.0.2 software (Sall 2001). For all other data, the correlation between psychological cohesiveness and innovativeness was tested by nonparametric procedure using Spearman coefficient.

The underlying hypothesis was that teams having high GDTF (local: psychological cohesiveness) scores within the context of psychological diversity have a tendency to positive correlation to design creativity. Furthermore, a study on psychological types which contributed significantly to innovativeness was conducted.

To examine correlation between GDTF and innovativeness, Spearman correlation analysis was performed. Spearman's correlation coefficient between psychological cohesiveness and innovativeness was 0.7979, values considered to be statistically significant ($P < 0.001$) and, therefore, highly reliable.

Scatterplot Matrix

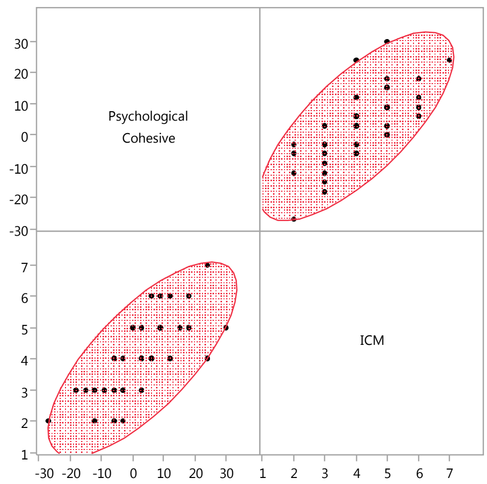


Figure 6-3 Spearman's Correlation Analysis: significant (<0.001) and positive correlation to innovativeness (Roh: 0.80)

Then ordinal logistic regression was conducted to scrutinize what types of personality contribute to innovativeness. As a process, the highest correlations with independent variables on a dependent variable and effective parameters were found. From multivariate correlation analysis, four out of eight different psychological types (EN, ET, EF, and IF) are finally selected and used in ordinal logistic regression.

Table 6.5 Correlation Analysis

	ES	**EN**	**IS**	**IN**	**ET**	**EF**	**IT**	**IF**
ES	1	-0.0376	0.127	-0.8578	0.1513	0.3683	-0.3141	-0.0943
EN	-0.0376	1	-0.8954	0.1348	-0.0507	0.0302	0.0471	0.1371
IS	0.127	-0.8954	1	0.0188	0.1021	0.1177	-0.0604	-0.0395
IN	-0.8578	0.1348	0.0188	1	-0.085	-0.1839	0.2858	0.2006
ET	0.1513	-0.0507	0.1021	-0.085	1	-0.0377	0.2768	-0.7378
EF	0.3683	0.0302	0.1177	-0.1839	-0.0377	1	-0.7873	0.2679
IT	-0.3141	0.0471	-0.0604	0.2858	0.2768	-0.7873	1	-0.0349
IF	-0.0943	0.1371	-0.0395	0.2006	-0.7378	0.2679	-0.0349	1

As the result of ordinal logistic regression, the p-values are significant with 95% confidence level, indicating that Extroverted (0.18, $p<0.0938$), Sensory (0.26, $p<0.0409$*), Feeling (0.04, $p<0.7571$), and Judging (0.38, $p<0.0016$*) are positively correlated with product innovation. Furthermore, regression coefficients are EN (-0.28, p<0.0456*), ET (-0.67, p<0.0274*), IF (-1.38, p<0.0002*), and EF (0.9, p<0.0001*). When the other variables are fixed, increasing one unit of EN in ME 2024 group causes decreasing log odds of design creativity by 0.28. Accordingly, ET and IF also decrease log odds of design creativity by 0.67 and 1.38 respectively. On the contrary, changing by one unit of EF increases log odds of improved design creativity by 0.9.

$$\mathbf{logit}\left(\frac{\boldsymbol{P_i}}{\mathbf{1}-\boldsymbol{P_i}}\right) = \boldsymbol{\beta_i} + \sum_{j=1}^{k} \boldsymbol{\beta_j} * \boldsymbol{x_j}$$

Eq. 6-1

where $\boldsymbol{x_1 = EN, x_2 = ET, x_3 = EF, x_4 = IF}$

$\beta_i = intercept\ of ICM = i + 1$

$P_i = P(ICM = i + 1)$

From correlation analysis results (table 6.5), Jung's Complementarity Rules, which stated that opposite pairs of each personality category have a negative relationship, were validated. From statistical analysis (table 6.6), IF, EF, and ET are significantly related to design creativity. Due to EN, ET, and IF having a negative relationship with product innovation, their complementary pairs, IS, IF, and ET, can be inferred to be positively related to innovativeness.

Table 6.6 Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept[2]	-16.009739	5.726941	7.81	0.0052*
Intercept[3]	-13.181459	5.558127	5.62	0.0177*
Intercept[4]	-11.255385	5.456715	4.25	0.0391*
Intercept[5]	-9.7304712	5.393127	3.26	0.0712
Intercept[6]	-7.396026	5.378987	1.89	0.1691
EN	-0.2810414	0.140599	4	0.0456*
ET	-0.6660789	0.301881	4.87	0.0274*
EF	+0.895818	0.223614	16.05	<.0001*
IF	-1.383928	0.365892	14.31	0.0002*

6.8 Creativity Index

Gough and Library (1981) developed experimental Creative Index (CI) for males, which is a linear transformation of MBTI score (Equation (6.2)). For algebraic notation, Gough puts I, N, F, and P as positive values. Then E, S, T, J are automatically determined by Jung's Complementarity Rules to be negative values. For instance, MBTI score I17, N35, T25, J15 would be written as (i, n, f, p) = (17, 35, -25, -15).

$$\text{Gough Creativity Index (Gough CI)} = 250 + 3*N + P - I - 0.5*F \quad \text{Eq. 6-2}$$

Responding to this method, a Creative Index (CI) for mechanical engineering teams is established. All parameters of Creativity Index (CI) were driven by a data set consisting of MBTI and ICM results. The particular solution of this over-determined system is:

$$\text{Park Creativity Index (Park CI)} = 3.28 - 0.01*N - 0.38*P - 0.33*I + 0.05*F \quad \text{Eq. 6-3}$$

Based on CI scores and ICM results, creativity levels are also defined. The table shows that the higher level, the more likely chance to produce innovative products.

Table 6.7 Creativity Level

Creativity Level	Range		
Level 1	2.33	3	Experimentally Determined i.e.: Level 1: Low. Level 7: High
Level 2	3.01	3.3	
Level 3	3.31	3.81	
Level 4	3.82	4.11	
Level 5	4.12	4.44	
Level 6	4.45	4.9	
Level 7	4.91	6.08	

6.9 Discussion and Conclusion

The psychologically diverse and cohesive teaming method, which is the core of Global Design Team Formation (GDTF), was briefly presented. Effectiveness of GDTF method was statistically validated from forty two teams′ final products evaluated by innovative characteristic metric (ICM). Further investigation into correlation analysis between psychological types and product innovation was conducted.

Statistical analysis outcomes revealed a significant correlation between product innovativeness and psychological cohesiveness within the context of psychological diversity. Among eight psychological types, Extraverted (″E″), Sensory (″S″), Feeling (″F″), and Judging (″J″) were positively correlated with product innovation. Extraverted Intuition (″EN″), Extraverted Thinking (″ET″), Extraverted Feeling (″EF″), and Introverted Feeling (″IF″) were significantly correlated to product innovation. Finally, a Creativity Index (CI) for mechanical engineering teams using personality traits was experimentally devised.

The results indicated that certain psychological types are more influential to design creativity and product innovation. Nevertheless, teams consisting of psychologically balanced and cohesive members are essential for expecting high performance. The generated Creativity Index (CI) in this study is only limited to use for predicting innovativeness of final products for mechanical engineering teams.

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Appendix E

List of participants the response from Teamology questionnaire for MBTI

CRN	Team Roster	MBTI							
	ME2024	e	i	j	p	s	n	t	f
94306	t1	5	0	3	2	5	0	5	0
		0	5	3	2	1	3	5	0
		2	2	4	1	3	2	3	2
	t2	3	2	4	1	3	2	3	2
		3	2	5	0	5	0	5	0
		4	1	5	0	4	1	3	2
	t3	3	2	5	0	5	0	3	2
		1	4	1	4	4	1	3	2
		5	0	4	1	4	1	4	1
	t4	2	3	0	5	5	0	3	2
		5	0	2	1	2	4	3	2
		4	1	4	1	2	3	1	4
	t5	2	3	2	3	4	1	5	0
		2	3	3	2	3	2	4	1
		4	1	4	1	3	2	1	4
	t6	1	4	2	3	0	5	5	0
		1	4	4	1	3	2	2	3
		5	0	1	4	1	4	3	2
	t7	3	2	4	1	1	4	2	3
		3	2	4	1	5	0	3	2
		5	1	5	0	5	0	5	0
	t8	5	0	4	1	4	1	4	1
		2	3	1	4	4	1	3	2
		4	1	1	4	2	3	4	1
	t9	4	0	4	1	5	0	1	4
		1	4	4	1	5	0	5	0
		2	3	3	2	4	1	3	2
	t10	2	3	4	1	4	1	5	0
		4	1	4	1	4	1	1	4
		2	3	3	2	4	1	4	1
94309	t11	5	0	1	4	3	2	4	1
		5	0	2	3	2	3	5	0
		2	3	3	2	2	3	3	2
	t12	3	2	3	2	5	0	3	2

		0	5	3	2	3	2	4	1
		1	4	5	0	5	0	5	0
	t13	2	3	3	3	3	2	4	1
		0	5	4	1	3	2	5	0
		4	1	2	3	4	1	2	3
	t14	3	2	4	1	4	1	3	2
		1	3	4	1	5	0	2	3
		2	3	3	2	1	4	2	3
	t15	4	1	5	0	5	0	5	0
		2	3	4	1	4	1	2	3
		5	0	1	4	2	3	4	0
	t16	4	1	1	4	3	2	4	1
		4	1	4	1	4	0	2	2
		3	2	2	3	2	3	3	2
	t17	4	1	1	4	4	1	1	4
		4	1	3	2	1	4	3	2
		1	3	2	3	5	0	3	2
	t18	2	3	1	4	5	0	3	2
		4	1	5	0	4	1	3	2
		5	0	2	3	1	4	4	1
	t19	0	5	5	0	5	0	5	0
		5	0	2	3	1	4	5	0
		4	1	2	3	3	2	2	3
94312	**t20**	1	5	3	3	4	0	5	4
		2	3	5	0	5	0	3	2
		2	3	3	2	3	2	3	2
	t21	1	4	4	1	3	5	2	4
		4	1	1	4	2	3	4	2
		4	1	2	2	4	0	4	1
	t22	4	1	2	3	4	1	1	3
		4	1	3	2	4	1	2	3
		4	1	1	4	3	2	3	2
	t23	3	2	3	2	4	1	3	2
		1	5	1	4	5	0	3	2
		4	1	2	3	3	2	2	3
	t24	3	0	3	2	3	3	1	4
		0	5	3	2	5	0	3	2
		4	1	3	2	4	1	1	0
94370	**t25**	5	0	2	3	5	0	5	0
		1	4	2	3	4	1	3	2
		1	4	3	2	4	1	4	0

	t26	2	5	5	0	5	0	5	3
		2	3	1	4	3	2	3	2
		5	0	3	2	2	3	2	3
	t27	0	5	5	0	3	2	3	2
		3	2	4	1	4	1	3	2
		2	1	4	1	2	2	4	1
	t28	5	0	5	0	2	3	4	1
		4	1	5	0	5	0	2	2
		1	4	3	2	5	0	3	2
	t29	5	0	4	1	5	0	2	3
		5	0	1	4	2	3	3	2
		3	2	3	2	4	1	4	1
	t30	2	3	1	4	5	0	5	0
		4	1	3	2	4	1	3	2
		4	1	4	1	5	0	3	2
	t31	5	0	3	2	5	0	5	0
		5	0	3	2	5	0	3	2
		3	2	5	0	5	0	3	2
	t32	5	0	0	4	3	2	5	0
		3	2	3	2	2	3	2	3
		3	2	5	0	4	1	4	1
94555	**t33**	5	0	3	2	5	0	1	4
		2	3	2	3	5	0	5	0
		3	2	4	1	4	1	4	1
	t34	3	2	0	5	1	4	5	0
		1	3	2	0	1	0	2	0
		3	3	2	4	3	2	5	1
	t35	0	5	5	0	5	0	4	1
		3	2	4	1	2	3	2	3
		3	2	2	3	2	2	4	0
	t36	2	4	5	1	4	4	3	3
		2	3	5	0	4	1	3	2
		0	2	4	0	3	5	4	3
	t37	5	0	3	2	1	4	5	0
		3	2	3	4	3	3	5	1
		2	3	2	3	3	2	4	1
	t38	3	2	1	4	4	2	2	3
		2	5	3	2	1	1	2	3
		2	1	5	1	2	2	4	1
	t39	3	2	4	1	3	2	3	2
		0	5	3	2	4	1	5	0

		1	4	1	4	3	2	3	2
		2	4	3	1	2	0	4	1
	t40	1	4	3	2	3	2	5	0
		1	4	4	1	5	0	4	1
		0	5	4	1	3	1	1	0
	t41	0	5	4	1	3	2	3	2
		1	5	4	1	5	2	5	0
		3	2	4	1	3	1	4	1
	t42	3	1	3	0	2	1	1	2
		3	2	3	1	5	1	3	2

*** This is the list of forty two teams of three sophomore students in Engineering Design and Economics (ME 2024) in Mechanical engineering at Virginia Polytechnic and State University. Teamology questionnaire was used to collect data and identify MBTI personality type.**

Appendix F

Results summary of cognitive functional modes and Innovative Characteristic Metric (ICM)

ME2024	ES	EN	IS	IN	ET	EF	IT	IF	ICM
t1	10.00	7.33	11.67	9.00	14.33	7.00	12.67	5.33	6
t2	11.67	5.67	14.33	8.33	15.33	10.67	9.33	4.67	5
t3	13.33	6.00	14.00	6.67	13.00	9.67	10.33	7.00	3
t4	12.00	10.67	9.33	8.00	10.33	11.00	8.33	9.00	4
t5	11.33	8.00	12.00	8.67	12.33	9.00	11.00	7.67	3
t6	7.67	12.33	7.67	12.33	11.33	8.00	12.00	8.67	2
t7	11.67	7.00	13.33	8.67	14.67	11.33	9.00	5.67	5
t8	13.33	10.00	10.00	6.67	13.00	8.33	11.67	7.00	3
t9	13.00	4.33	15.33	6.67	12.00	10.00	9.67	7.67	5
t10	12.00	6.00	14.00	8.00	13.00	9.67	10.33	7.00	5
t11	11.67	12.33	7.67	8.33	14.00	8.00	12.00	6.00	2
t12	11.33	4.00	16.00	8.67	13.00	7.00	13.00	7.00	4
t13	11.00	7.67	12.67	9.33	12.33	7.67	12.67	8.00	2
t14	10.00	6.67	13.00	9.67	10.33	11.00	8.67	9.33	5
t15	12.67	8.00	12.00	7.33	14.33	9.00	10.33	5.00	4
t16	12.33	9.67	9.67	7.00	12.00	9.33	10.00	7.33	5
t17	12.67	9.33	10.33	7.00	9.67	10.33	9.33	10.00	3
t18	12.67	9.33	10.67	7.33	13.00	9.67	10.33	7.00	4
t19	11.00	9.00	11.00	9.00	14.00	8.00	12.00	6.00	4
t20	11.33	4.67	15.33	8.67	12.67	10.67	12.67	10.67	2
t21	11.33	10.67	10.33	9.67	12.00	10.00	11.00	9.00	3
t22	14.33	9.67	10.33	5.67	10.00	11.33	8.00	9.33	5
t23	13.67	7.67	12.67	6.67	10.00	9.33	11.00	10.33	3
t24	12.33	7.00	13.00	7.67	8.67	9.33	7.33	8.00	4
t25	13.67	6.33	13.67	6.33	12.67	6.00	13.33	6.67	3
t26	11.67	8.33	12.33	9.00	12.67	11.33	11.33	10.00	3
t27	8.33	5.67	13.00	10.33	12.67	9.33	10.00	6.67	6
t28	12.00	6.00	14.00	8.00	13.67	11.00	8.33	5.67	7
t29	14.00	9.33	10.67	6.00	13.00	11.00	9.00	7.00	4
t30	15.00	6.33	13.67	5.00	13.33	8.67	11.33	6.67	4
t31	15.67	5.67	14.33	4.33	15.33	10.67	9.33	4.67	6
t32	11.67	9.67	10.00	8.00	13.67	9.00	10.67	6.00	6
t33	14.67	6.00	14.00	5.33	13.00	9.67	10.33	7.00	5
t34	8.67	9.33	7.33	8.00	11.67	4.33	13.67	6.33	3
t35	9.33	6.67	12.67	10.00	12.33	8.33	11.00	7.00	6
t36	9.00	8.33	15.00	14.33	12.67	11.33	10.00	8.67	4
t37	11.00	12.33	9.00	10.33	15.33	7.33	14.00	6.00	3

t38	9.33	8.00	10.33	9.00	10.67	10.00	10.33	9.67	4
t39	10.33	7.00	13.00	9.67	11.33	6.67	13.33	8.67	3
t40	9.33	4.00	14.00	8.67	13.33	6.00	14.00	6.67	3
t41	8.67	4.67	16.33	12.33	10.33	5.67	12.00	7.33	3
t42	10.33	5.67	11.67	7.00	11.67	9.67	7.67	5.67	4

*** This is the summary of team average in cognitive functional modes (ES, EN, IS, IN, EF, ET, IF, IT) from personality styles (E, I, J, P, S, N, T, F) and results of Innovative Characteristic Metric (ICM).**

Chapter 7

(Manuscript #4) Employing Teamology in an International Setting to Improve Engineering Team Performance

Abstract

This paper explores effectiveness of psychological teaming method in an international setting. To do so, student teams from a transatlantic National Science Foundation (NSF) Research Experiences for Undergraduates (REU) program and global collaborative engineering design teams participated in this experiment. Global Design Team Formation (GDTF) score, which is combination of Teamology and Kogut-Singh Index, was introduced to provide psychological cohesiveness and cultural similarity. With psychological perspective, overall performance and cohesiveness of NSF-REU were analyzed to identify what types of cognitive functional modes are correlated. In global collaborative course, teams′ products were evaluated by Innovative Characteristic Metric (ICM) to see how psychologically cohesive and culturally similar teams contribute to product innovativeness. Statistical results from NSF-REU revealed that overall performance and team cohesiveness have positive correlation with decision making and information collection mode respectively. On the other hand, global collaborative course results showed that there was a significant difference between the control (low GDTF score) and the subject group (high GDTF score). Global Design Team Formation (GDTF)′s eligibility to forecast team performance was demonstrated in this study.

Keyword: Psychological Teaming, Design Creativity, Global Collaboration

7.1 Introduction

Teamology, developed by Douglass J. Wilde of Stanford University, is a psychological organization method. The method combines Jung′s cognitive functional mode theory and Belbin′s role theory to form teams with balanced personality diversity. Teamology has been shown to significantly improve the quality of work produced by teams of US graduate mechanical engineering students working together on design projects within the same course. Nevertheless, it must be proven that employing Teamology in global use is effective.

Higher labor productivity, more revenue from global offshore outsourcing, and availability of specific technical skills can result from globally distributed and culturally diverse teams (Joseph (2005). A socio-cultural framework is essential for the success of effective teaming tuned for creativity in global collaboration. Accordingly, a computational method which links the psychological and socio-cultural theories to achieve effective global virtual teams is also demanded. This new approach may escalate the value of current Teamology without compromising on performance in global context.

Therefore, this paper provides psychological perspective on global collaboration and introduces the Global Design Team Formation (GDTF) method, a computational method combining Teamology and the Kogut and Singh index (KS index) using the Global Leadership and Organization Behavior Effectiveness (GLOBE) dataset. Then, the ability of GDTF to account for this cultural diversity in predicting team performance is discussed in this paper.

7.2 Backgrounds

In Teamology, individuals′ psychological types are identified from a survey consisting of 20 questions. It determined each individual′s Myers-Briggs Typology Index (MBTI). MBTI is composed of four categories of preference: Extrovert (E) versus Introvert(I), Sensing(S) versus iNtuitive (N), Thinking (T) versus Feeling (F), and Judging (J) versus Perceiving (P) (McCaulley, 1976, 1981).

Extraverted (E)	Introverted (I)
Sensing (S)	Intuitive (N)

Thinking (T)	Feeling (F)
Judging (J)	Perceiving (P)

Figure 7-1 MBTI Dichotomies

Table 7.1 Conversion Formula

	Teamology (2009)	
	C-MODE	**D-MODE**
Measurement	ES=EI-JP+2SN, EN=EI-JP-2SN, IS=-EN, IN=-ES ,where EI=E-I, JP=J-P, SN=S-N	EF=EI+JP-2TF, ET=EI+JP+2TF, IT=-EF,IF=-ET , where EI=E-I, JP=J-P, TF=T-F

Extraverted Sensing (ES)	Extraverted Intuition(EN)	Extraverted Thinking (ET)	Extraverted Feeling (EF)
Introverted Sensing (IS)	Introverted Intuition (IN)	Introverted Thinking (IT)	Introverted Feeling (IF)

Figure 7-2 Eight Cognitive Modes

Through the conversion formula (Table 7.1), participants' 8 cognitive functional modes scores are determined. Finally, through this process, the participants are distributed across the teams to cover all cognitive functional modes (Figure 7-2). By doing so, team creativity is enhanced and this method has been validated throughout more than decades in Mechanical Engineering at Stanford University.

7.3 Global Design Team Formation Method (GDTF)

For success in international setting, GDTF combined Teamology and GLOBE as the theoretical foundations for the new approach. Unlike Teamology, the GDTF measures the extent to which team members are psychologically cohesive and culturally similar each other within the context of diversity.

And, the GDTF score can be obtained by combining scores from members' psychological relationship using MBTI type and the Kogut and Singh index (KS index) from GLOBE.

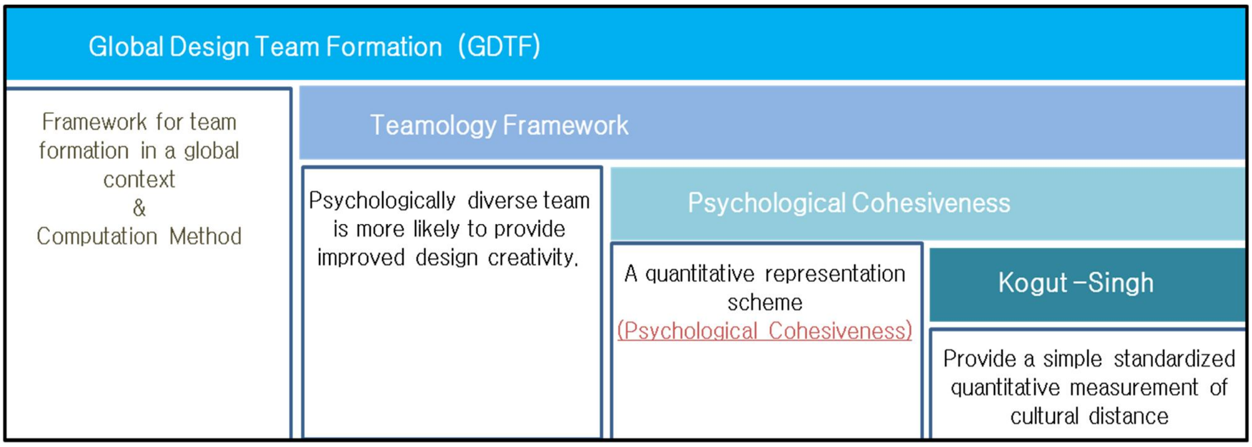


Figure 7-3 Global Design Team Formation (GDTF) Method

7.4 Research Method

National Science Foundation (NSF) Research Experiences for Undergraduates (REU) program and Global Collaborative Engineering Design Course (ME 5664) were conducted to see if GDTF is appropriate to predict team performance in creativity.

The primary research questions were:

1. What cognitive functional modes (collection and decision making mode) are significantly correlated to overall performance and team cohesiveness in NSF-REU program?

2. How does the psychologically cohesive and culturally similar teaming technique (GDTF) contribute to global collaboration projects? Furthermore, is the GDTF more capable to predict team performance in an international setting?

7.4.1 NSF-REU

Dyadic teams, each consisting one US undergraduate mechanical engineering student and one graduate mechanical engineering student serving as a mentor, performed fulltime research together over a period of eight weeks. This collaboration occurred in the context of a transatlantic National Science Foundation (NSF) Research Experiences for Undergraduates (REU) program located at Virginia Tech (USA) and

Technische Universität Darmstadt (Germany). These teams were formed during summers 2011, 2012, and 2013, and their performances and cohesiveness were measured following these sessions.

7.4.2 Global Collaborative Design Course

Global collaborative engineering design course assembled psychologically cohesive and culturally similar teams of 10-11 students from China, Germany, Mexico, and USA. Student teams, formed by GDTF, designed Electric Networked Vehicle (EN-V) of General Motors Company. As default conditions, each team was composed of geographically dispersed and culturally diverse members, and each team targeted different markets. Then, final teams′ products were evaluated by Innovative Characteristic Metric (ICM) to measure creativity.

Table 7.2 Team Composition Results from Multi-National Group

Team 1			Team 2			Team 3			Team 4		
a5	SJTU	structure	a29	VT	structure	a45	TUD	structure	a37	SJTU	structure
a53	SJTU	structure	a54	VT	structure	a31	TUD	structure	a50	VT	structure
a9	TUD	structure	a19	MTY	structure	a59	TUD	structure	a27	TUD	structure
a4	TUD	structure	a1	MTY	structure	a41	VT	structure	a26	TUD	structure
a15	MTY	Exterior	a43	HU	Exterior	a25	VT	structure	a17	MTY	Exterior
a34	MTY	Exterior	a44	HU	Exterior	a23	SJTU	Exterior	a58	MTY	Exterior
a32	VT	Exterior	a7	TUD	Exterior	a8	SJTU	Exterior	a38	VT	Exterior
a13	VT	Exterior	a35	TUD	Exterior	a20	MTY	Exterior	a42	VT	Exterior
a18	TUD	Interior	a16	SJTU	Interior	a30	MTY	Exterior	a49	SJTU	Interior
a46	TUD	Interior	a51	SJTU	Interior	a47	HU	Interior	a12	SJTU	Interior
						a40	HU	Interior			

*TUD: Technischen Universität Darmstadt; HU: Howard University, VT: Virginia Tech, MTY: Monterrey Tech; SJTU: Shanghai Jiao Tong University

7.5 Result and Discussion

Statistical analysis was performed by JMP 10.0.2 software (Sall, 2001). Twenty three transatlantic NSF-REU teams and eight global collaborative design teams participated in this experiment. Underlying hypotheses are: For NSF-REU teams, overall team performance and team cohesiveness are related to either the information collection or decision-making mode; For global collaborative course teams, teams having higher GDTF score outperform teams with lower scores.

7.5.1 NSF-REU

Twenty three dyadic teams′ overall performance and team cohesiveness were analyzed. In addition, Collection-Mode and Decision-Making modes of teams (Table 7.1) were measured to investigate which cognitive functional modes are correlated to overall performance and team cohesiveness. Ordinal logistic regression was conducted to address what types of cognitive functional modes contributed to overall performance and cohesiveness. Statistical analysis results indicated that decision making mode (3.22, $p < 0.0433^*$) was significant and positively correlated to overall performance (Table 7.3). On the other hand, information collection mode (3.20, $p < 0.0682$) was close to significant level and has positive correlation to team cohesiveness (Table 7.4).

Table 7.3 Ordinal Logistic Fit for Overall Performance in NSF-REU

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept[4]	-3.2388734	1.161946	7.77	0.0053*
Intercept[3]	-0.0575848	0.8591694	0.00	0.9466
D-Dist(%)	3.22489276	1.5958317	4.08	0.0433*
C-Dist(%)	-1.2299073	1.657725	0.55	0.4581

Table 7.4 Ordinal Logistic Fit for Team Cohesiveness in NSF-REU

Parameter Estimates

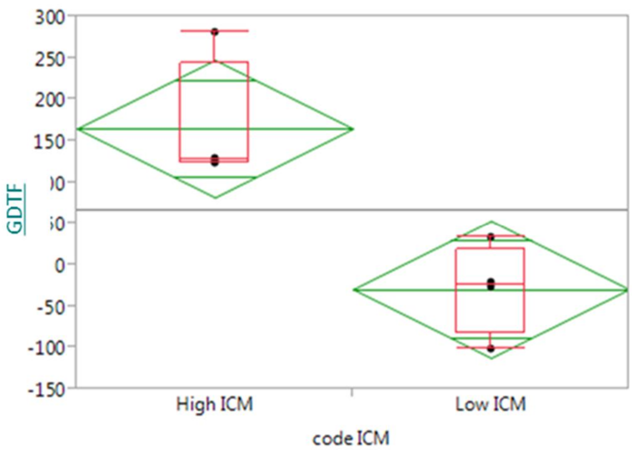
Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept[4]	-2.2747149	1.0407791	4.78	0.0288*
Intercept[3]	0.72400972	0.8778027	0.68	0.4095
D-Dist(%)	-1.0143914	1.414732	0.51	0.4734

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
C-Dist(%)	3.20558044	1.7575724	3.33	0.0682

7.5.2 Global Collaborative Design Course

For statistical analysis, eight global collaborative design teams′ products were evaluated by Innovativeness Characteristic Metric (ICM). Then ICM results coded into two groups: the control group consisted of teams having lower ICM, and the subject group was composed of teams having higher ICM. From T-test (t=-4.06, p<0.0041*), there is statistically significant evidence that a group of high ICM has a different GDTF from a group that has low ICM. Therefore, psychologically cohesive and culturally similar teams within the context of diversity have a greater chance to produce innovative products than teams that do not.

Table 7.5 Summary of T-Test and Mean/Standard Deviation



Difference	-194.25	t Ratio	-4.05696
Std Err Dif	47.88	DF	5.416529
Upper CL Dif	-73.96	Prob > |t|	0.0083*
Lower CL Dif	-314.54	Prob > t	0.9959
Confidence	0.95	Prob < t	0.0041*

Level	Number	Mean	Std Dev
High ICM	4	165.00	78.0385
Low ICM	4	-29.25	55.5000

Additionally, Spearman correlation analysis was performed to examine correlation between GDTF and innovativeness, and the coefficient was Rho =0.8961 (P < 0.0026). Therefore, GDTF score, which represents teams′ psychological cohesiveness and cultural similarity, is statistically significant and highly correlated each other.

7.6 Discussion and Conclusion

This paper examined effectiveness of psychological teaming method in an international setting with two different experiments: a transatlantic National Science Foundation (NSF) Research Experiences for

Undergraduates (REU) program and the global collaborative design course. In NSF-REU, statistical results indicated that overall performance and team cohesiveness have positive correlation with decision making and information collection modes respectively. With respect to the global collaborative design course, the more psychologically cohesive and culturally similar teams are, the greater the chance to produce innovative products. Further correlation analysis results supported these findings. GDTF score as an index to predict team performance in global collaboration was demonstrated in this study.

NSF-REU teams′ performance is determined by a number of factors such as academic performance, skill set, and experience. NSF-REU program, indeed, is not clearly targeted at design creativity. Therefore, it is hard to evaluated team performance with a psychological teaming technique. Selecting best fitting candidates meeting program requirement has to be preceded for achieving the NSF-REU goal.

Global Design Team Formation (GDTF)′s qualification as team creativity index was successfully shown in this study. Yet, only eight teams, which is a not enough sample size to ensure statistical validity (Hogg, 2006), implemented in effectiveness and correlation analysis of GDTF and team creativity. Therefore, adding more data from experiments will provide reliable and reasonable results.

7.7 Acknowledgement

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Appendix G

Results summary of National Science Foundation (NSF) - Research Experiences for Undergraduates (REU) program

Team	Performance	Cohesive	C-Distance	D-Distance	C-Dist(%)	D-Dist(%)
nsf11t01	2	3	1.8	0.5	91%	25%
nsf11t02	3	3	0.54	0.54	27%	27%
nsf11t03	4	3	0.36	1.22	18%	61%
nsf11t04	3	3	1.41	1.7	71%	86%
nsf11t05	2	4	0.45	0.1	23%	5%
nsf12t01	3	3	0.3	0.1	15%	5%
nsf12t02	3	3	1.26	0.22	64%	11%
nsf12t03	3	4	1.84	1.41	93%	71%
nsf12t04	3	4	0.92	1.46	47%	74%
nsf12t05	3	3	0.1	0.2	5%	10%
nsf12t06	3	4	1.8	1.81	91%	91%
nsf12t07	3	3	0.3	0.5	15%	25%
nsf12t08	2	3	0.22	0.41	11%	21%
nsf12t09	2	3	1.4	0.22	71%	11%
nsf13t01	2	2	0.1	0.22	5%	11%
nsf13t02	2	2	1.12	1.94	56%	98%
nsf13t03	4	2	1.22	1.71	61%	86%
nsf13t04	4	3	1.12	1.98	56%	100%
nsf13t05	3	3	1.66	1.5	84%	76%
nsf13t06	3	4	1.3	1.65	66%	83%
nsf13t07	3	3	1	1.7	51%	86%
nsf13t08	2	2	0.54	1.6	27%	81%
nsf13t09	3	4	1.98	1.71	100%	86%

*** Twenty three dyadic teams' overall performance and team cohesiveness were collected from graduate mentors to analyze underlying factors between cognitive functional mode distance (*collection mode (C-Mode) and decision-making mode (D-Mode)*) and team effectiveness.**

Appendix H

List of participants the response from questionnaire for MBTI

Team			MBTI								GLOBE	ICM
			e	**i**	**j**	**p**	**s**	**n**	**t**	**f**	**Country**	
2012	Team1 (Chevrolet)	a7	5	0	3	2	4	1	4	1	13	3
		a12	4	1	3	2	3	2	4	1	62	
		a19	5	0	3	2	4	1	5	0	62	
		a23	0	5	5	0	4	1	4	1	58	
		a29	3	2	5	0	5	0	4	1	26	
		a35	1	4	4	1	3	2	3	2	26	
		a39	2	3	4	1	4	1	4	1	58	
		a41	4	1	3	2	3	2	4	1	26	
		a42	4	1	5	0	2	3	3	2	26	
		a43	2	3	3	2	3	2	5	0	26	
		a47	2	3	1	4	4	1	3	2	62	
		a50	3	2	3	2	3	2	4	1	13	
		a51	3	2	4	1	3	2	2	3	62	
		a54	3	2	3	2	3	2	4	1	26	
	Team 2 (Buick)	a4	4	1	3	2	5	0	3	2	62	7
		a9	2	3	4	1	3	2	5	0	13	
		a15	1	4	4	1	2	3	4	1	13	
		a16	4	1	3	2	4	1	1	3	26	
		a24	1	4	5	0	4	1	2	3	26	
		a25	1	4	4	1	5	0	2	3	26	
		a27	1	4	3	2	3	2	4	1	26	
		a45	3	2	2	3	1	4	3	2	62	
		a46	2	3	5	0	2	3	3	2	26	
		a49	3	2	2	3	3	1	4	1	26	
		a53	4	1	3	2	5	0	3	2	62	
		a57	5	0	2	3	3	2	3	2	62	
		a58	2	3	2	3	5	0	5	0	62	
		a60	5	0	3	4	5	2	3	2	62	
	Team 3 (Adam Opel)	a5	0	5	3	2	5	0	2	3	62	6
		a6	3	2	4	1	5	0	2	3	13	
		a8	2	3	1	4	4	1	2	3	13	
		a10	5	0	4	1	5	0	0	5	37	
		a11	5	0	4	1	4	1	5	0	62	
		a13	4	1	2	3	2	3	4	1	13	
		a18	3	2	3	2	4	1	4	1	62	

		a21	3	2	5	0	5	0	3	2	26	
		a22	4	1	3	2	1	4	3	2	13	
		a30	2	3	3	2	5	0	3	2	26	
		a31	2	3	3	2	3	2	3	2	26	
		a32	3	2	3	2	3	2	3	2	26	
		a33	1	4	3	2	5	0	4	1	26	
		a34	4	1	2	3	5	0	3	2	26	
		a59	1	4	2	3	4	1	3	2	26	
	Team 4 (Daewoo Patac)	a14	3	2	5	0	3	2	4	1	4	3
		a17	5	0	1	4	4	1	4	1	62	
		a20	2	3	2	3	5	0	3	2	13	
		a26	1	4	5	0	5	0	3	2	26	
		a28	4	1	4	1	3	2	4	1	26	
		a36	2	3	4	1	4	1	2	3	26	
		a37	2	3	3	2	3	2	2	3	26	
		a38	0	5	5	0	1	4	5	0	26	
		a40	2	3	1	4	2	3	5	0	26	
		a44	2	3	3	2	4	1	2	3	26	
		a48	2	3	3	2	5	0	3	2	42	
		a52	2	3	5	0	3	2	5	0	62	
		a55	3	2	3	2	1	4	3	2	62	
		a56	5	0	4	1	4	1	3	2	13	
2013	Team 5 (Chevrolet)	a5	3	2	4	1	3	2	4	1	26	6
		a53	4	1	4	1	2	3	4	1	26	
		a9	3	2	3	2	4	1	2	3	58	
		a4	4	1	4	1	5	0	3	2	58	
		a15	2	3	2	3	2	3	1	4	13	
		a34	3	2	4	1	3	2	4	1	13	
		a32	0	5	4	1	4	1	3	2	62	
		a13	0	5	4	1	4	1	3	2	62	
		a18	5	0	2	3	2	3	1	3	26	
		a46	1	4	3	2	4	1	3	2	26	
	Team 6 (Buick)	a29	0	5	5	0	0	5	5	0	62	5
		a54	5	0	3	2	5	1	4	1	62	
		a19	3	2	1	4	4	1	3	2	13	
		a1	5	0	2	3	4	1	2	3	13	
		a43	3	2	3	2	5	0	4	1	62	
		a44	2	3	5	3	4	2	3	2	62	
		a7	1	4	5	0	5	0	4	1	26	
		a35	3	2	4	1	4	1	2	3	26	
		a16	3	2	4	0	4	1	4	1	26	

		a51	4	1	4	1	2	3	4	1	26	
	Team 7 (Opel)	a45	4	1	2	3	4	1	5	2	58	2
		a31	4	1	2	4	5	0	5	0	58	
		a41	5	0	4	1	4	1	3	2	62	
		a25	4	1	2	3	3	2	5	0	62	
		a23	2	3	5	0	3	2	4	1	26	
		a8	1	4	5	0	0	5	2	3	26	
		a20	5	0	2	3	4	1	4	1	13	
		a30	2	3	4	1	3	1	4	1	13	
		a47	2	4	2	4	5	0	3	2	26	
		a40	2	4	1	4	4	1	3	2	26	
	Team 8 (Daewoo Patac)	a37	2	3	3	1	0	5	3	2	26	3
		a50	1	4	2	3	5	0	3	2	26	
		a27	3	2	4	1	5	0	3	2	58	
		a26	4	2	5	2	2	4	4	2	58	
		a17	2	3	3	2	5	0	1	4	13	
		a58	4	0	3	2	4	1	5	2	13	
		a38	1	4	2	3	4	1	3	2	62	
		a42	5	0	4	1	3	2	3	2	62	
		a49	3	2	3	2	3	2	4	1	26	
		a12	1	4	4	1	4	1	3	2	26	

*** Results summary of eight global collaboration teams from SJTU, TUD, MTY, and VT are presented. Under IRB approval, MBTI information was collected from Teamology questionnaire with coded name. Additionally, nationality was gathered from GLOBE dataset (see more detail in Appendix C).**

Appendix I

The list of nationality information with nine-dimension from GLOBE dataset

Country	Number	4	13	26	37	42	58	62
	Name	**India**	**Mexico**	**China**	**Ireland**	**France**	**Germany**	**USA**
Nine Dimensions from GLOBE	**uncsa**	4.15	4.18	4.94	4.30	4.43	5.22	4.15
	futsa	4.19	3.87	3.75	3.98	3.48	4.27	4.15
	powsa	5.47	5.22	5.04	5.15	5.28	5.25	4.88
	indsa	4.38	4.06	4.77	4.63	3.93	3.79	4.20
	humsa	4.57	3.98	4.36	4.96	3.40	3.18	4.17
	achsa	4.25	4.10	4.45	4.36	4.11	4.25	4.49
	Trisa	5.92	5.71	5.80	5.14	4.37	4.02	4.25
	malsa	2.90	3.64	3.05	3.21	3.64	3.10	3.34
	aggsa	3.73	4.45	3.76	3.92	4.13	4.55	4.55

Chapter 8

Discussion and Conclusions

This dissertation has presented a theoretical framework and an associated novel computational method, the *Global Design Team Formation* (GDTF) method, for forming creative design teams in a globally distributed and culturally diverse environment. The GDTF method predicts team performance using individual personality trait measurements, established cultural traits, and overriding skill sets. The personality traits are measured based on Meyers-Briggs Type Indicator (MBTI), abbreviated based on Teamology theory. The cultural traits are derived from the Kogut-Singh (KS) index using the GLOBE dataset. The overriding skill sets are accommodated using the Extended Fuzzy Analytical Hierarchy Procedure (EFAHP). The team creativity performance is measured using the Innovative Characteristic Metric (ICM). The method has been developed and validated using three data sets: teams composed of US mechanical engineering students; teams composed of mechanical engineering students from the US, Germany, Mexico, and China; and teams composed of US and German mechanical engineering students.

Taken together, this research represents an important step towards achieving the fundamental understanding necessary to develop a practical method for forming effective, high-performance engineering design teams in a global context.

This chapter concludes this dissertation with a series of concluding remarks, a summary of its contributions, and suggestions for future research.

8.1 Discussion and Concluding Remarks

This section will first briefly discuss the limitations on the research conducted for this dissertation. Next, it will share some interesting observations that were made concerning the data collected. Finally, it will summarize the answers to the research questions posed in Chapter 1.

8.1.1 Limitations

The following will briefly discuss the quality of the data sets used in this dissertation research, including the limitations on statistical analysis that this quality imposes.

The data for the US undergraduate mechanical engineering students (ME 2024) was obtained from one course over three semesters. The course was team-taught each semester, and several of the course sections were taught by the same instructors over this period of time. The concept generation, screening, and selection methodologies, and the assignments and the metrics by which the assignments were graded, were the same for all the sections. One reviewer not associated with the course evaluated all the designs using the ICM metric. A second reviewer not associated with the course or the dissertation research reviewed a subset of the designs to validate the consistency of the first reviewer with respect to the ICM metric (Cronbach′s alpha = 0.92). Hence, combined with the large sample size (126 students in 42 teams) and the homogeneity of the participants, the quality of this dataset is excellent with respect to establishing the correlation between personality types and creativity in engineering design.

The data for the global collaborative engineering design course (ME 5664) was obtained over three fall semesters. Each semester had four teams of approximately 12 students each. These 12 students were from the US, Germany, Mexico, and China. The instructors, assignment, and grading metrics were the same for all the teams of this period of time. The same reviewer for ME 2024 reviewed these team designs using the same ICM metric. MBTI data was collected for the last two years, and the GDTF method was applied to these 8 teams. MBTI data was not collected for the first year, so the GDTF method was not applied to those first four teams; only the ICM metric was applied. Hence, the relatively small sample size (8 teams with MBTI data), the complexity of the team composition (different educational systems, cultural differences, age diversity of participants), and the relative small impact of cultural traits (13%) compared to personality traits (87%) on team performance (Kirby et al., 2007), suggests that ongoing data collection is needed to increase confidence in the integration of cultural traits using the KS index with the GLOBE data set.

The data for the US undergraduate mechanical engineering students working with German graduate mechanical engineering students in dyadic teams (NSF REU) was obtained over a period of three summers. The team effort involved research and not engineering design. Hence team cohesiveness and team performance were measured; creativity was not measured. The German graduate student on each team evaluated the team cohesiveness and performance. The data size (23 teams) was significant but insufficient for statistical analysis with a high confidence level.

8.1.2 **Observations on the Data Collected**

Within the pool of US sophomore mechanical engineering students (ME 2024) used in this dissertation research, the Jung psychological types *judging* (J), *sensing* (S), *extraversion* (E), and *feeling* (F), were found, in declining order of importance, to be correlated with engineering design creativity (see Section 6.7 for details). However, only J and S had a 95% confidence level. Likewise, the cognitive functional modes *introverted feeling* ("IF"), *extraverted feeling* ("EF"), *extraverted thinking* ("ET"), and *extraverted intuition* ("EN"), were found, in declining order of importance, to be correlated with engineering design creativity (see Section 6.7 for details). While all these modes had a 95% confidence level, only EF had a positive correlation. Hence, one would expect that those with strong J, S, and/or EF personality types would be important contributors on a team engaged in engineering design creativity.

The negative correlation of IF, ET, and EN personality types with engineering design creativity implies that those with strong IF, ET, or EN type scores are unlikely to contribute positively to the team. Hence, if IF, ET, or EN personality types are desired for diversity, then those with weak scores in these types should be selected.

Since IF and ET are opposites, and both carry a negative correlation to engineering design creativity, one would typically seek candidates with weak scores in these types, with a preference for a weak ET score since the IF carries a stronger negative correlation.

The negative correlation associated with the EN personality type suggests that the opposite personality type, namely, IS, is preferred. This is an interesting result because the IS personality type is otherwise not thought of in the literature as being conducive to engineering design creativity—and 72% (91 of 126) of the US undergraduate mechanical engineering students sampled had this personality type!

Taking a closer look at the distribution of personality types of the US mechanical engineering students compared to the general US population reveals the following observations: 42.8% of the US mechanical engineering students were _STJ dominant (i.e., ESJT and ISJT combined) compared to 26.1% of the US population when scaled for similar gender distribution. This clearly shows that the personality of mechanical engineers differs significantly from that of the general population, and that one would therefore expect that the creative design results from these engineers to differ from the general population.

Creativity researchers have traditionally valued the ability to generate ideas, and they have thus found the psychological personality types *intuition* (N), *perceiving* (P), *extraversion* (E), and *thinking* (T), in declining order of importance, to correlate to this task (Gough, 1981). Shah (2003), however, points out that creativity in engineering design must consider other factors than idea generation alone and therefore must draw on other personality types. It is therefore reasonable that this dissertation research has identified *judging* (J), *sensing* (S), *extraversion* (E), and *feeling* (F), in declining order of importance, as more relevant to creativity in engineering design.

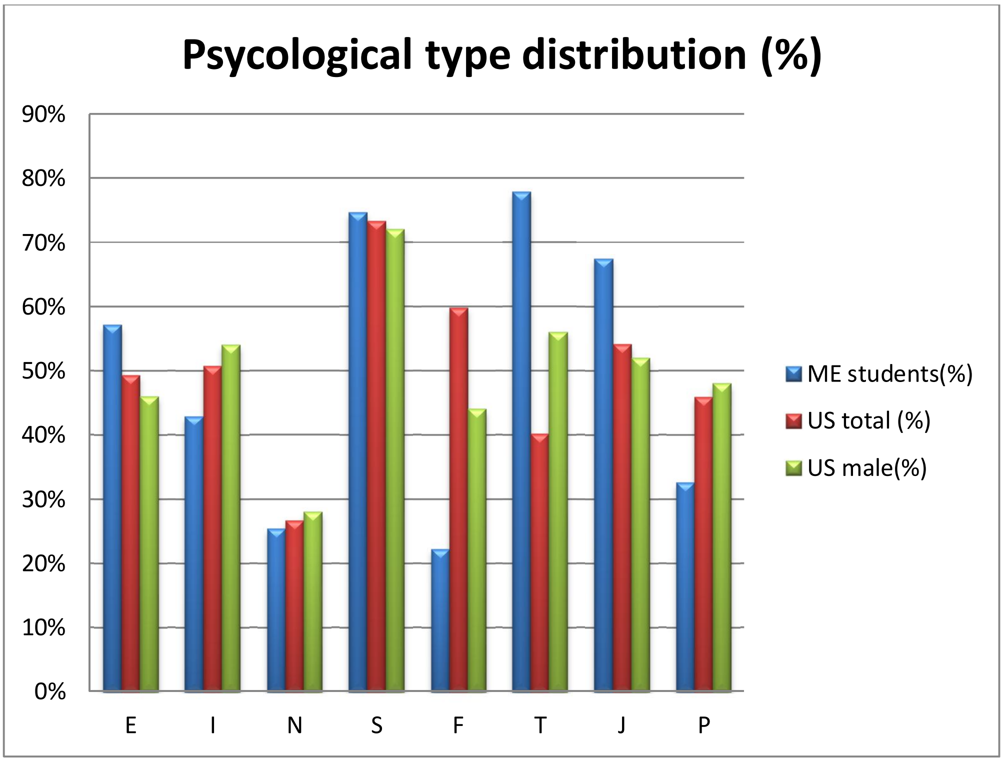

Figure 8-1 Distribution of personality types in among US mechanical engineering students (n=126, approximately 10% women), compared to the male and overall populations in the USA (Kendall & McHenry, 1998)

Table 8.1 Distribution of personality types in among US mechanical engineering students (n=126, approximately 10% women), compared to the male and overall populations in the USA (Kendall & McHenry, 1998). The "US 90% male" is scaled from US males and US total.

	E	**I**	**N**	**S**	**F**	**T**	**J**	**P**
ME students	57%	43%	25%	75%	22%	78%	67%	33%
US males	46%	54%	28%	72%	44%	56%	52%	48%
US total	49%	51%	27%	73%	60%	40%	54%	46%
US 90% male	47%	53%	28%	72%	47%	53%	52%	48%
DIFFERENCE	+10	-10	-3	+3	-25	+25	+15	-15

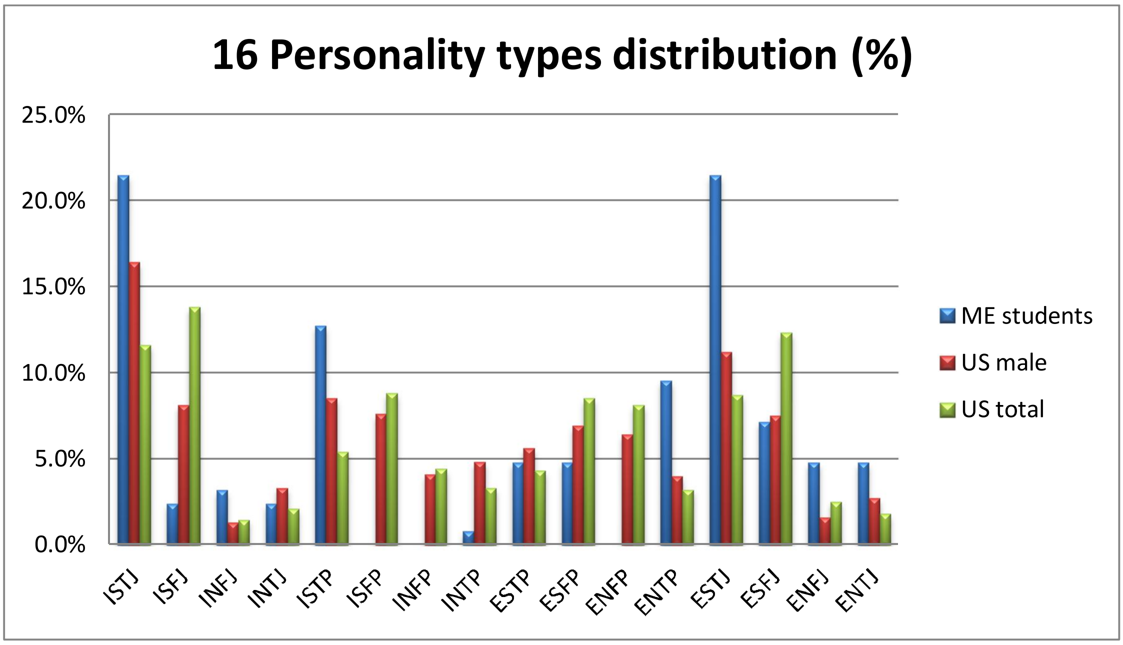

Figure 8-2 Distribution of personality types in among US mechanical engineering students (n=126, approximately 10% women), compared to the male and overall populations in the USA (Kendall & McHenry, 1998)

Table 8.2 Distribution of personality types in among US mechanical engineering students (n=126, approximately 10% women), compared to the male and overall populations in the USA (Kendall & McHenry, 1998). The "US 90% male" is scaled from US males and US total.

Personality Types	**ME students**	US males	US total	**US 90% male**	**DIFFERENCE**
ISTJ	21.4%	16.4%	11.6%	15.4%	+6.0
ISFJ	2.4%	8.1%	13.8%	9.2%	+6.8
INFJ	3.2%	1.3%	1.5%	1.3%	+1.9
INTJ	2.4%	3.3%	2.1%	3.1%	-0.7
ISTP	12.7%	8.5%	5.4%	7.9%	+4.8
ISFP	0.0%	7.6%	8.8%	7.8%	-7.8
INFP	0.0%	4.1%	4.4%	4.2%	-4.2
INTP	0.8%	4.8%	3.3%	4.5%	-3.7
ESTP	4.8%	5.6%	4.3%	5.3%	-0.5
ESFP	4.8%	6.9%	8.5%	7.2%	-2.4

ENFP	0.0%	6.4%	8.1%	6.7%	-6.7
ENTP	9.5%	4.0%	3.2%	3.8%	+5.7
ESTJ	21.4%	11.2%	8.7%	10.7%	+10.7
ESFJ	7.1%	7.5%	12.3%	8.5%	-1.4
ENFJ	4.8%	1.6%	2.5%	1.8%	+3.0
ENTJ	4.8%	2.7%	1.8%	2.5%	+2.3

8.1.3 **Research Questions**

The follow subsections will briefly summarize the answers to the research questions that were posed in Chapter 1 of this dissertation.

8.1.3.1 Research Question 1

QUESTION: *What are the primary challenges with regards to team effectiveness in global collaborative design projects?*

The primary challenges in global collaborative engineering design were addressed in Chapter 3. These are: cultural differences; unclear goals and objectives; different performance evaluation standards and procedures; and technological infrastructure incompatibilities. Recommendations to overcome these challenges include: increasing cultural competence among team members; establish clear and common goals and objectives; ensure common evaluation standards and procedures; and ensure a common, compatible, and similar quality technology infrastructure.

8.1.3.2 Research Question 2

QUESTION: *How can personnel be systematically grouped to form effective, global collaborative, and creative design teams using individual personality trait measurements and established cultural traits?*

Chapter 4 detailed the development of the *Global Design Team Formation* (GDTF) method. It combines individual measured personality traits based on MBTI and abbreviated based on Teamology theory, with cultural traits derived from the KS index using the GLOBE dataset.

8.1.3.3 Research Question 3

QUESTION: *Extending team formation based on individual personality trait measurements and established cultural traits, how can the proposed methodology be extended to accommodate special, overriding skill sets?*

Chapter 5 detailed the use of the EFAHP decision-making procedure to integrate overriding skill into the GDTF method. The resulting procedure has been coded in MATLAB to provide a practical graphical user interface to assist in the team formation task.

8.1.3.4 Research Question 4

QUESTION: *Which personality traits correlate to creativity in engineering design? And can these traits be used to predict team creativity?*

Chapter 6 examines experimental data that has been collected of a period of three years to answer these questions. This includes personality type data for team members and their team design work. By evaluating the creativity of their team design work using the ICM metric, a correlation between personality traits and the creativity of engineering design has been developed. The dominant correlation to creativity in engineering design are the *judging* (J) and *extraversion* (E) personality types, and to a lesser degree the *feeling* (F) and *sensing* (S) personality types. This correlation, in the form of a creativity index, named the *Park Creativity Index* (Park CI), can thus be used to predict the creative ability of a team based on the team members' individual personality traits.

8.1.3.5 Research Question 5

QUESTION: *Are the methods developed for creative design team formation, based individual personality trait measurements and established cultural traits, applicable to other datasets?*

In Chapter 7, the GDTF method is validated by applying it to a dataset of US undergraduate mechanical engineering students working with German graduate students in dyadic team. Statistical analysis shows that overall performance and team cohesiveness are significantly correlated with the cognitive functional modes.

Chapter 7 also describes the effect of applying the GDTF method to the formation of teams in a global course with each team having members in the US, Germany, Mexico, and China. Statistical analysis shows a significant improvement in engineering design creativity performance with the introduction of the GDTF method.

8.2 Contributions

This dissertation research has made the following contributions:

1. **Framework for team formation in a global context:** Building on the existing Teamology framework, which is based on Jung′s and Belbin′s role theories, this dissertation integrated the effect of cultural traits to the personality traits used in Teamology to adapt it for use in a global context. The new framework also adds the integration of the ability to accommodate special skillsets (e.g., technical skills, cultural insights, or language skills) within a team.

2. **Computational method implementing the framework:** The *Global Design Team Formation* (GDTF) method was developed to implement the above framework. This method has been coded using MATLAB to provide a graphical user interface to make it easier to employ this method.

3. **Creativity index:** The correlation between personality traits and creativity in engineering design has been identified, and has been described in the form of a new creativity index, the Park creativity index (Park CI), in which creativity is measured using the ICM metric. This new index validates the claim by Shah (2003) that the definition of creativity used by cognitive researchers does not apply to the domain of engineering design.

8.3 Future Research

This dissertation research has made important contributions to the field of team formation with an emphasis on improving the quality of creativity in engineering design, including in a global context. It has also identified area where addition insight and research is desired. This section outlines these areas of future research.

Global Collaborative Engineering Design (ME 5664):

The data sets for the course on global collaborative engineering design (ME 5664) is currently too small to reliably analyze the correlation between creativity and personality traits in a global context. This is particularly true given the diversity of cultures involved and the relative small impact that cultural traits is thought to have on team performance. Hence there is a need to continue data collection for this course for several more years, probably 5-6 more years, in order to achieve the statistical confidence needed. The challenge will be to retain the nature of these team projects and assignments such that variability is not introduced over this long time period.

Engineering Creativity vs. Engineering Research:

The GDTF method and the two data sets used for its calibration (ME 2024, ME 5664) targets creativity in engineering design. Using the resulting GDTF method in the selection process for matching undergraduate students with research projects (NSF REU) assumes that the correlation between personality types and creativity in engineering design applies to engineering research. One might expect this to be true because some level of innovation is needed in engineering research to discover novel solutions, as is the need to be systematic in processing customer needs. However, this similarity remains to be confirmed. There is therefore a need to examine this correlation both in an all-domestic environment, and to increase the ongoing data collection performed in this dissertation research to confirm the impact of cultural traits in engineering research.

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Appendix J-IRB

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MEMORANDUM

DATE:	October 19, 2012
TO:	Yongseok Park, Jan Helge Bohn
FROM:	Virginia Tech Institutional Review Board (FWA00000572, expires May 31, 2014)
PROTOCOL TITLE:	Teamology for Globally Distributed, Culturally Diverse Engineering Teams
IRB NUMBER:	12-779

Effective October 18, 2012, the Virginia Tech Institution Review Board (IRB) Chair, David M Moore, approved the New Application request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

http://www.irb.vt.edu/pages/responsibilities.htm

(Please review responsibilities before the commencement of your research.)

PROTOCOL INFORMATION:

Approved As:	**Expedited, under 45 CFR 46.110 category(ies) 7**
Protocol Approval Date:	**October 18, 2012**
Protocol Expiration Date:	**October 17, 2013**
Continuing Review Due Date*:	**October 3, 2013**

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

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MEMORANDUM

DATE:	September 18, 2013
TO:	Yongseok Park, Jan Helge Bohn
FROM:	Virginia Tech Institutional Review Board (FWA00000572, expires April 25, 2018)
PROTOCOL TITLE:	Teamology for Globally Distributed, Culturally Diverse Engineering Teams
IRB NUMBER:	**12-779**

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