AN ABSTRACT OF THE THESIS OF

Friederich A. Berthelsdorf for the degree of Master of Science in Mechanical Engineering presented on July 7, 2017.

Title: How Personality Affects Creativity in Concept Ideation

Abstract approved: _____

Robert B. Stone

This thesis uses the manuscript option, and consists of a previously-published paper and a paper that has been accepted for publication.

Manuscript One details an independent confirmatory study to Choo et al. (2014), which demonstrated that correlations exist between personality type and the outcome of concept ideation methods. This is confirmed by conducting a similar experiment with a larger sample size. Four concept ideation techniques were selected from those used in the previous research: individual and group brainstorming, and individual and group mind mapping. 90 junior level engineering design students completed a Meyers-Briggs Type Indicator (MBTI) sorter and concept ideation activities using each of the four ideation methods. The creativity of the output was measured with metrics for the quality, quantity, and variety of ideas produced. The resulting dataset was statistically analyzed to find how individual output from these activities correlated with MBTI results to investigate how personality type correlates with the creativity of output from concept ideation methods.

Manuscript Two begins investigating the concept of team personality (the average personality of the team along each MBTI spectrum) and the effect it has on ideation creativity. We find evidence suggesting that a team whose average personality falls near the extremes of the Thinking-Feeling spectrum will produce more creative results, a team that is neutral along the Introversion-Extraversion spectrum can choose their method based on which creativity metric they wish to maximize, and a team with high personality variance can select a method create either more variety or higher quantity of ideas.

How Personality Affects Creativity in Concept Ideation

by
Friederich A. Berthelsdorf

A THESIS

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Master of Science thesis of Friederich A. Berthelsdorf presented on July 7, 2017

APPROVED:

Major Professor, representing Mechanical Engineering

Head of the School of Mechanical, Industrial, and Manufacturing Engineering

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Friederich A. Berthelsdorf, Author

PUBLICATION THESIS OPTION

This thesis is presented in accordance with the Manuscript Document Format option. Two manuscripts are provided. The first was published in the 2016 International Conference on Design Creativity. The second paper was accepted for publication in the ASME 2017 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference Proceedings.

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- I would also like to thank Robert B. Stone for supporting and advising me during my time at Oregon State University.
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CONTRIBUTION OF AUTHORS

Ryan M. Arlitt assisted with every part of the 2016 ICDC paper. Jessica L. Armstrong and Abigail M. Wilson assisted with the analysis for the 2016 ICDC paper.

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GENERAL INTRODUCTION

Creativity is often used interchangeably with innovation in the popular press. In this work, we consider creativity as an individual skill that can be brought to bear on a design effort to produce an innovative product or result. Creativity is typified in the concept generation (or ideation) phase of an engineering design process. Techniques exist for concept ideation that intend to enhance individual creativity skills and support a more thorough exploration of the solution space. As individuals have preferences for learning methods, which can be correlated to personality type, this research explores the possibility that individual and team (or group) personality correlates with specific types of concept ideation techniques. If there is a correlation, then designers can use their preferred ideation technique to their advantage based on the goal of the concept ideation exercise.

In this thesis, two manuscripts are presented – one published and one accepted for publication. These detail research findings on the correlation between personality and concept ideation technique. The first manuscript validates and extends prior research (Choo et al., 2014), which showed that there was a correlation between MBTI personality type (Kiersey and Bates, 1984; Kiersey 1998) and the outcome of concept ideation techniques as measured by three metrics: quality, quantity, and variety. These same metrics were used in this study to quantify the results of concept ideation using the same techniques studied in Choo et al (2014).

The second manuscript extends the research by focusing on aggregated team personality rather than individual. It shows that the studied teams with a high variance of personality type tended to produce higher quality concepts, and can choose between methods to increase the quantity of variety of their concepts.

Why study this?

This research addresses concept ideation, an integral part of the design process that has direct bearing on a product's level of innovation. Concept ideation is a process that cannot be optimized (in a traditional sense), insofar as it is impossible to know that the best possible idea has been identified. However, there are still potential improvements that can be made to the concept ideation process that exploit individual creativity preferences. The personality of the ideator(s) is an avenue for improvement that had not been considered until Choo et al. (2014),

and their research is verified in the first manuscript presented here, and is extended to aggregated team personalities in the second manuscript.

FIRST MANUSCRIPT

CREATIVE PERSONALITIES: HOW PERSONALITY INFLUENCES CREATIVITY OF CONCEPT IDEATION METHODS

Friederich A. Berthelsdorf, Ryan M. Arlitt, Jessica L. Armstrong, Abigail M. Wilson, and Robert B. Stone

The Fourth International Conference on Design Creativity (4th ICDC)
Atlanta, GA, November 2nd-4th, 2016

Abstract

This paper details an independent confirmatory study to Choo et al. (2014), which demonstrated that correlations exist between personality type and the outcome of concept ideation methods. We confirm previous research by conducting a similar experiment with a larger sample size. Four concept ideation techniques were selected from those used in the previous research: individual and group brainstorming, and individual and group mind mapping. A larger sample size consisting of 90 junior level engineering design students completed a Meyers-Briggs Type Indicator (MBTI) sorter and concept ideation activities using each of the four ideation methods. The creativity of the generated output was measured with metrics for the quality, quantity, and variety of ideas produced by each method. The resulting dataset was statistically analysed to find how individual output from these activities correlated with MBTI results to investigate how personality type correlates with the creativity of output generated by concept ideation methods.

1. Introduction

Ensuring innovative products as a direct result of applying a design method is one of the holy grails of engineering design. Innovative products follow from techniques that foster creativity in concept generation and there are numerous methods of attempting to stimulate creative designs.

Previous research has investigated the connections between personality and creativity (Batey & Furnham, 2006), and the Meyers-Briggs Type Indicator (MBTI) has been accepted as a useful tool for forming teams in engineering education (Jensen et al., 2000), but little research has been performed on how MBTI types will influence performance of engineering tools (Choo et al., 2014). This research is intended to reduce the difficulties of choosing concept generation methods by determining which methods work well for differing personality types. As a result, designers may be able to pick and choose those tools that will produce the best results for them, rather than simply picking a tool at random. Conversely, with knowledge of personality preferences that perform best with a certain creativity tool, designers may be able to place themselves into the appropriate personality ‘mindset’ to better exploit a given tool.

1.1. Exploratory vs confirmatory studies

This paper reports on an independent confirmatory study of the significant correlations found in Choo et al. (2014). In this work we test for the significance of correlations found in Choo et al.

(2014), and only using an MBTI sorter rather than both MBTI and the Six Thinking Hats model (Jensen et al., 2000). Furthermore, performing this confirmatory study after the exploratory study is published mitigates the risk of p-hacking: the repeated re-analysis of the experimental data such that spurious correlations are more likely to be found as significant. As a consequence of these two factors, the significant results of this work carry validity that is not possible with a single study.

2. Background

In 1923, Carl Jung postulated that there are psychological functions that can be used to categorize a person into a psychological type (Jung, 1923). These functions, and their countering functions, were Thinking vs. Feeling and Sensing vs. Perceiving, and were modified by an attitude type: Introversion vs. Extroversion.

Jung's work was used by Katharine Cook Briggs and her daughter, Isabel Briggs Myers as the basis for their highly successful MBTI test in the 1940s. The MBTI test is intended to reveal preferences on four different scales (Introversion (I) vs. Extroversion (E), Intuition (N) vs. Sensing (S), Thinking (T) vs. Feeling (F), and Judging (J) vs. Perceiving (P)) rather than producing a definitive model of a personality (Quenk & Hammer, 1998). A person's MBTI type is given by stating the sides of the scales that the person falls on, e.g. ISTJ. Where this paper states a partial type (e.g. IT), it refers to all MBTI types that exhibit those preferences. For example, EF refers to the set of ENFJ, ENFP, ESFJ, and ESFP. This paper focuses on the I/E and F/T axes, as the sample has relatively few N or P types.

Other, more detailed models of personality have emerged in the psychology research community. For instance, the Big Five model of personality is one of the most favored by the psychology academe (Barrick & Mount, 1991). It bears some familiar elements of the MBTI sorter but captures additional nuances that researchers thought the non-academic team of Meyers-Briggs overlooked. However, for purposes of application, the MBTI sorter has proven descriptive of personality and useful in establishing the personality makeup of design teams, which has led to its acceptance as an aid for team formation and the selection of leaders (Roush & Atwater, 1992).

2.1. Concept generation

Concept generation is one of the first steps in creating a new design, and can be performed with no prior work aside from identifying the problem. As a result, concept generation requires little setup before it can be used in an experiment.

There is a high variety among the numerous concept generation methods. Among them are morphological analysis and several methods of brainstorming, including brainwriting, mind mapping, the 6-3-5 method, and C-Sketch. This research focused on brainwriting and mind mapping, incorporating team and individual versions of each. Although there is evidence that there are benefits to performing multiple methods in succession (Brown & Paulus, 2002), this research only considers each method in isolation.

Brainstorming is one of the most common methods of concept generation, and involves simply writing ideas without censoring or censuring either your own or other participants' ideas, as well as building off previous ideas and trying to generate "wild ideas" (Litchfield 2009).

Mind mapping involves the creation of a graph where the nodes are individual ideas or related concepts, and the edges show how the nodes are related.

2.2. Creativity

Creativity has been defined many different times in many different ways (Batey & Furnham, 2006), and there have been various attempts to state a qualitative measurement system for creativity. J. Shah investigated the usage of three team idea generation techniques using 44 subjects (Shah, 1998) and has created some metrics for measuring creativity in concept generation (Shah et al., 2003). The metrics used for this research measure quality, quantity, and novelty/variety, and are described below:

2.2.1. Quantity

This metric is simply the number of ideas generated by a participant using a single method during a single session.

2.2.2. Quality

Quality is a quantification of the applicability of a concept to solve the given problem. Quality of a concept is difficult to objectively assess. For this study, a rubric was created to categorize the quality of the ideas generated. Unfortunately, as there are multiple dimensions of quality, a comprehensive quality rubric is difficult to create: Kudrowitz & Wallace (2013) mention usefulness, relevance, appropriateness, novelty, clarity, workability, and feasibility. The rubric used in this research (see Table 2.1) is intended to rate each concept along the dimensions of relevance, possibility, specificity, and level of detail, similar to the rubric of Choo et al. (2014).

Table 2.1. The rubric used to assess the quality of a generated concept.

Score	Level	Detail	Example (sample problem: get someone to do a task)
0	Irrelevant to the problem		Take a nap
1	Not a possible solution		Time travel and do it last week
2	Valid but nonspecific solution	Low	Bribe with food
3		High	Buy lunch Friday
4	Specific valid solution	Low	Buy Pizza
5		Medium	Buy pizza from Dominos
6		High	Buy a large pepperoni pizza from Dominos at noon Friday

2.2.3. Novelty/Variety

Novelty is a measure of the uniqueness of an individual solution. Novelty was assessed by combining similar concepts into bins (e.g. vehicles) and sub-bins (e.g. airplanes and automobiles). A single researcher binned all the concepts, attempting to keep a consistent level of detail of sub-bins between the responses to the design prompts. The number of items in each bin (including sub-bins) was used to determine the novelty of each item in the bin using equation 1 (Chan, et al., 2011).

$$Novelty = \frac{(C_t - C_b)}{C_t} \times 10 \quad (1)$$

Where $C_t =$ the total number of concepts generated for a design prompt, and $C_b =$ the number of items in the same bin as an idea (including sub-bins).

Variety is a measure of how different the concepts are within a group of responses to a design prompt. So that comparisons could be made, this paper follows the example of Choo et al. (2014), where variety was calculated as the average novelty of a person's concepts.

3. Methodology

The target population of this study consisted of the students in a junior-level mechanical engineering design course at Oregon State University. The 94 students each took a 70 question MBTI preference sorter (most of them were sorted into SJ, particularly ISTJ, as shown in Table 2.2), and 90 of them voluntarily chose to participate in at least one session. During the course, MBTI information was used to put the students into 3 to 4 person teams that were then used for the team ideation methods. As the research was to take place during the scheduled class, the ideation sessions were each limited to 15 minutes; this included explanation of the ideation method, presentation of the design prompt and 10 minutes of practice, after which the students indicated whether they wished their data to be used for the study, and their results were collected.

As the population for this study consisted of student engineers, it is not surprising that the population leaned heavily toward SJs in general, and ISTJs in particular. Unfortunately, the sparseness of the data for personality types N and P means that any conclusions drawn for those personality axes from this dataset would have been less well founded.

Table 2.2. **The number of participants sorted into each MBTI type**

		Sensing (S)		**Intuition (N)**	
		Feeling (F)	**Thinking (T)**	**Feeling (F)**	**Thinking (T)**
Extroversion (E)	**Judging (J)**	ESFJ 10	ESTJ 9	ENFJ 1	ENTJ 3
	Perceiving (P)	ESFP 2	ESTP 0	ENFP 1	ENTP 0
Introversion (I)	**Judging (J)**	ISFJ 12	ISTJ 37	INFJ 1	INTJ 2
	Perceiving (P)	ISFP 4	ISTP 4	INFP 2	INTP 2

As four lab sections met for the course, the ideation methods used by the previous study were narrowed down to four:

- individual brainstorming (I-BS),
- group brainstorming (G-BS),
- individual mind mapping (I-MM), and
- group mind mapping (G-MM).

To minimize confounding factors, it was decided that each week a different design prompt would be given, and each of the four lab sections would use a different ideation method each week. All four ideation methods were used for each design prompt, allowing external confounding factors such as scheduled events to be combined with the confounding factor of using different design prompts.

Four design prompts were created for this study. While reusing the same prompt for all ideation methods invites the most direct comparisons between these methods, having an individual see the same prompt multiple times would introduce learning effects. In order to mitigate learning effects while still maintaining a valid basis for comparison, we used four different design prompts that are roughly comparable in scope and specificity. These problems were designed to be similar enough to invite meaningful comparisons, while different enough to mitigate learning effects.

The design prompts and a selection of responses (concepts) follow; the selection includes a) a common response, b) an unusual response, and c) a rare response.

1. Generate concepts that will allow zoogoers to interact with zoo animals.
    a. Feeding the animals
    b. Learn animal calls
    c. Put on a guard dog suit and pay to get mauled by a tiger/lion
2. Generate concepts that will bring supplies to remote areas.
    a. Airplane
    b. Submarine
    c. Trained turtle with supplies strapped to shell

3. Generate concepts that will help a farmer gather his crops.
    a. Tractor
    b. Autonomous crop-picking robots
    c. Ninja cats steal diamonds to allow farmers to buy new equipment
4. Generate concepts that improve the experience of travelling as a passenger.
    a. Food
    b. Xbox/PS4 in vehicle
    c. Lots of puppies on board to play with

4. Analysis

In this section, five of the comparisons in the Choo et al. (2014) paper are retested using the new data. The previous study found several correlations (1) between the types of ideation methods and quantity of concepts and (2) between individuals' personality preference and ideation method performance for quality and variety measures. The five Choo et al. (2014) correlations for which we gathered data are compared against this confirmatory study's correlations in Table 2.3. All tests are one-sided, with interval data (quantity, variety) undergoing t-tests and ordinal data (quality) undergoing Mann-Whitney U tests.

Table 2.3. p-value comparison between studies

Creativity Metric	Correlation	Choo et al. p value	Our p value	Do the studies agree?
Quantity	I-MM > I-BS (all personality types)	0.008	0.007	Agree
	I-MM > G-BS (all personality types)	0.015	4.6E-8	Agree
	G-BS vs I-BS (EF only)	0.15 for G-BS > I-BS	0.004 for I-BS > G-BS	Conflict
Variety	IT > ET (G-BS only)	0.01	0.36	Agree
Quality	G-MM (EF vs IT)	0.01 for EF > IT	0.16 for IT > EF	Conflict

To mitigate the risk of p hacking, we applied a Bonferroni correction to our p value for significance. We started from the standpoint that a p value of 0.05 showed significance, and divided that by the number of tests, in this case five, for a significance level of 0.01. Our results confirm that I-MM tends to produce a higher quantity of output than I-BS or G-BS, but our results do not show similar significance levels for the MBTI type comparisons (the quality and variety comparisons in Table 2.3).

Where Choo et al. (2014) showed near significance for EFs producing higher quantity in group brainstorming over individual brainstorming, our study showed strong significance for the opposite. The disagreement in this case is most likely due to a single outlier from the Choo et al. (2014) study who produced 43 concepts in G-BS, while the study's average quantity for EFs using G-BS without the outlier was 7.8 (Choo et al., personal communication). The larger participant size of this study bolsters our claim that EFs actually produce a higher quantity of concepts using the individual brainstorming ideation method, but this result should be viewed with caution in light of the disagreement between studies.

4.1. Quantity

The quantity of results by ideation method is shown in Fig. 1 and agrees with the results from Choo et al. (2014). Not only was I-MM found to significantly outperform I-BS ($p=0.0069$), but I-BS significantly outperformed G-BS ($p=0.0023$), and G-BS significantly outperformed G-MM ($p=0.0015$). This suggests a definite rank ordering of ideation methods exists when using quantity as the metric. Stated another way, if the quantity of unique concepts is the sole metric of importance, individual ideation methods outperform group ideation methods. Curiously, though, mind-mapping outperforms brainstorming for the quantity metric on an individual level, but the opposite is true in a group ideation setting. This could be indicative of mind-mapping's ability to effectively chart and guide an individual's recall of stored knowledge versus trying to chart a multi-minded group's thoughts or knowledge.

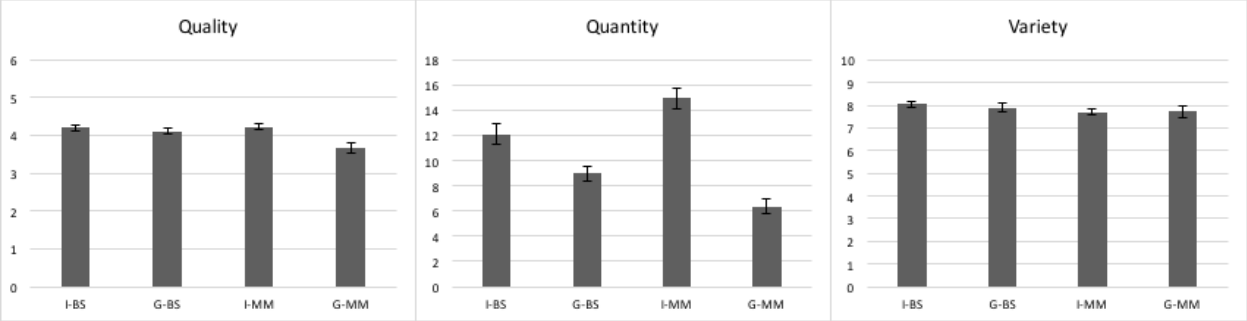

Figure 2.1. The average quality, quantity, and variety of concepts generated by each ideation method. Error bars are ±one standard error.

4.2. Quality

Inter-rater reliability of the quality rubric was calculated using a stratified random sample. For each design prompt, ten design concepts were randomly sampled and distributed to three raters: an engineering design post-doctoral researcher, an engineering design graduate student, and a computer science undergraduate. Krippendorff's alpha was calculated for this sample, revealing low inter-rater reliability for the quality rubric (α=0.4301). Low inter-rater reliability in this case can likely be attributed to inadequate rater training prior to their evaluation and raters of very different levels of design experience and expertise. Additionally, the chosen rating scheme combining relevance, feasibility, specificity, and validity into a single ordinal quality scale caused disagreements. For example, the solution of "mutant crops that gather themselves" is both specific and relevant, but differing interpretations and opinions on feasibility resulted in ratings of 1 and 5 on the 0-6 quality scale. Nonetheless, the full quality results are presented in Fig. 2.1.

The results from the Mann-Whitney U tests show that, when using quality as the metric, G-BS and I-BS are not significantly different (p=0.33). And while G-MM is significantly worse than I-MM (p=0.0002) and G-BS (p=0.019), I-MM and G-BS are not significantly different from each other (p=0.097) (as depicted in Fig. 1). Notably, the low inter-rater reliability may have impacted these results.

4.3. Variety

The tests for variety, shown in Fig. 1, revealed significance only for the test of I-BS and I-MM (p=0.024) with I-BS producing higher variety than I-MM. As noted in Section 4.1, individual brainstorming may produce more variety since the ideation method is intended to induce jumps

throughout the solution space. Conversely, the individual mind-mapping ideation method may encourage a more logical, ordered examination of solutions resulting in a slightly lower variety score. For this study, the ideation sessions were limited to ten minutes. The time limit, rather than the ideation methods themselves, may have impacted the results as more variety might emerge under longer session lengths.

4.4. Results by MBTI type

As shown in Figure 2.2, there were several significant findings in the data when categorized by the three personality types used in Choo et al. (2014) – extroverted thinkers (ETs), introverted thinkers (ITs) and extroverted feelers (EFs). The quality metric showed that ETs have a significant advantage over EFs when using G-MM ($p=0.042$). If mind-mapping provides an accurate model of recalling stored knowledge, then the extroverted thinkers should fare better with the logical ideation method. The variety metric showed that ITs have a significant advantage over ETs when using G-MM ($p=0.017$). In this finding, the more structured approach of mind-mapping may support introverted thinkers in expressing their more carefully considered internal ideation method.

The quantity metric revealed more surprising results and conflicted with the Choo (2014) findings. When using G-BS, ITs have a significant advantage over EFs ($p=.00014$), and possibly an advantage over ETs ($p=0.059$). This goes against the conventional wisdom that extroverts have an intrinsic advantage in group activities over introverts. A plausible explanation for this result is that the extroverts in the group may take on the role of a facilitator rather than an active idea generator. Furthermore, still using the quantity metric, EFs have a significant advantage over ETs when using I-BS ($p=0.040$), and when using I-MM ($p=0.044$).

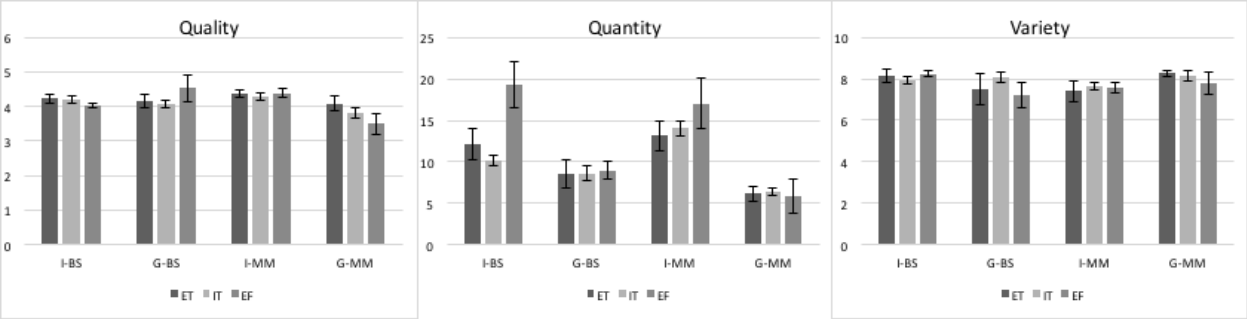

Figure 2.2. The average quality, quantity, and variety for concepts generated by each ideation method, broken down by the personality types used in Choo et al. (2014). Error bars are ±one standard error.

5. Conclusions

In this paper, we presented results from a confirmatory study of Choo et al. (2014), and results we obtained that confirm many of their findings related to differences between ideation methods. For example, we find that I-MM produces a significantly higher quantity of concept results than I-BS or G-BS. However, our results differ when comparing personality types and their preferences for certain ideation methods. In the case of the quantity metric when looking at I-BS and I-MM as used by EFs, Choo et al. (2014) reported a p value of 0.15 (suggesting that I-BS might be better than G-BS). This conflicts with our finding of a p value of 0.004 in the other direction (suggesting that G-BS is significantly better than I-BS). Given the larger sample size (n=90) of this study, we have confidence that these differing findings are more likely representative of the designer population. The full results are summarized in Table 2.3.

In general, there is evidence to support that certain ideation methods will yield improved results in the quantity (I-MM) and quality (I-BS, G-BS, and I-MM) of concepts. No significant differences were observed between the ideation methods for the measure of variety. Finally, there is evidence to support that certain personality types tend to prefer (or achieve better results with) certain ideation methods.

5.1 Future Work

Future work will include looking at the effects of each individual axis of personality, removing confounding factors, and identifying reasons for the discrepancies between this study and Choo et al. (2014). There are also numerous other opportunities for future work. The primary objective

should be to increase the sample size, especially of the under-represented MBTI types. However, there are likely inferences and significant findings to be found in the data collected for this research.

Additional avenues of research beyond this data set include:

- Other personality tests, such as Six Hats and Big 5
- Other ideation methods
- Differences due to team personality make-up
- Performing different ideation methods in succession
- Tasks aside from concept ideation
- Evaluating team results for the concept ideation task
- Evaluating specific portions of a concept ideation technique to discover how an ideation method could be built to provide a specific personality or team of personalities with the best chances for a high output (measured by a specific metric).

SECOND MANUSCRIPT

CREATIVITY OF CONCEPT IDEATION AS AFFECTED BY TEAM PERSONALITY

Friederich A. Berthelsdorf and Robert B. Stone

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Abstract

Prior work has shown that individual MBTI personality type influences the creative output of concept ideation methods (Berthelsdorf and Stone, 2016, Choo et al. 2014). In this paper, we present a pilot study that investigates the concept of team personality (defined as the average personality of the team along each MBTI spectrum) and the effect it has on ideation results, as measured by three creativity metrics; quantity, quality, and variety. We find evidence suggesting that a team whose average personality falls near the extremes of the Thinking-Feeling spectrum will produce more creative results, a team that is neutral along the Introversion-Extraversion spectrum can choose their method based on which creativity metric they wish to maximize, and that a team with high personality variance can choose to create either more variety or higher quantity of ideas based on their selected method.

Introduction

Concept ideation is a critically important part of the design process, but it is typically highly dependent on the skill level of the designer or design team. However, concept ideation can be improved regardless of skill, such as by Brown and Paulus (2002) who found that variety of ideas can be improved by using a group concept ideation method followed by an individual concept ideation method. This paper, as with Choo et al. (2014) and Berthelsdorf and Stone (2016), tries to improve concept ideation by studying the effects of ideator personality at a team level on the creativity outcome of concept ideation techniques. This paper investigates another facet of the research introduced in Berthelsdorf et al. (2016) and, as such, a similar background review and methodological approach is utilized.

The connections between personality and creativity have been investigated previously (Batey & Furnham, 2006), and the Meyers-Briggs Type Indicator (MBTI) has been accepted as a beneficial tool for forming teams in engineering education (Jensen et al., 2000), but little research has been performed on how the performance of engineering tools and methods are influenced by the MBTI types of the user (Berthelsdorf and Stone, 2016, Choo et al. 2014). This paper investigates the concept of a team personality as an indicator of concept ideation results, and can be used to reduce the difficulties of choosing concept generation methods by determining which methods work well for differing personality types that make up a design team. This allows design teams to pick and choose those tools that will produce the best results for them, rather than simply

using a random tool. Conversely, with knowledge of personality preferences that produce better results (by a chosen metric) with a certain creativity tool, design teams may be able to place themselves into the appropriate personality 'mindset' to get better results with a given tool.

Background

Carl Jung postulated that there are psychological functions that can be used to categorize people into psychological types (Jung, 1923). These functions, and their countering functions, were Thinking vs. Feeling and Sensing vs. Perceiving, and were modified by an attitude type: Introversion vs. Extraversion.

Isabel Briggs Meyers and Katherine Cook Briggs used Jung's work as the basis for their MBTI test in the 1940s. The MBTI test is intended to reveal preferences on four different scales (Introversion (I) vs. Extraversion (E), Intuition (N) vs. Sensing (S), Thinking (T) vs. Feeling (F), and Judging (J) vs. Perceiving (P)). It is important to note that the 16 possible personality descriptions resulting from a MBTI test show preferences rather than producing a definitive model of a personality (Meyers, et al., 1998). A person's MBTI type is given by stating the sides of the axes that the person falls on, e.g. ISTJ. Where this paper states a partial type (e.g. IT), it refers to all MBTI types that exhibit those preferences. For example, EF refers to the set of ENFJ, ENFP, ESFJ, and ESFP. This paper focuses on the I/E and F/T axes, as the sample has relatively few N or P types.

Other, more detailed models of personality have been produced by the psychology research community. The Big Five model of personality is one of the most favored by the psychology academe (Barrick and Mount, (1991). It bears some familiar elements of the MBTI sorter but captures additional nuances that researchers thought the non-academic team of Meyers and Briggs overlooked. However, for purposes of application, the MBTI sorter has proven descriptive of personality and useful in establishing the personality makeup of design teams, which has led to its acceptance as an aid for team formation and the selection of leaders (Roush and Atwater, 1992).

Concept Generation

Concept generation, or concept ideation, is one of the first steps in creating a new design, and can be performed with no prior work aside from identifying the problem. As concept generation occurs so early in the design process, it is often difficult and costly to return to this

phase after a design has begun. It is therefore necessary to obtain as good results as possible from this phase of the design process. Additionally, concept generation requires little setup before it can be used in an experiment.

There is high variety among the numerous concept generation methods. Among the methods are morphological analysis and several types of brainstorming, including brainwriting, mind mapping, the 6-3-5 method, and C-Sketch (Ullman, 2016). This research focused on brainwriting (hereafter referred to as brainstorming) and mind mapping, incorporating team and individual versions of each. Although there is evidence that there are benefits to performing multiple methods in succession (Brown and Paulus, 2002) this research only considers each method in isolation.

Brainstorming is one of the most common methods of concept generation, and involves simply writing ideas without censoring or censuring either your own or other participants' ideas, as well as building off previous ideas and trying to generate "wild ideas" (Litchfield, 2009).

Mind mapping involves the creation of a graph where the nodes are individual ideas or related concepts, and the edges show how the nodes are related.

Creativity

Creativity has been defined many times in different ways (Batey and Furnham, 2006), and there have been various attempts to create a qualitative measurement system for creativity. J. Shah investigated the usage of three team idea generation techniques using 44 subjects (Shah, 1998) and created metrics for measuring creativity in concept generation (Shah et al., 2003). The metrics used for this research measure quality, quantity, and novelty/variety, as described below:

Quantity is simply the number of ideas generated by a participant using a single method during a single session. For this paper, this is averaged over the team to find a team quantity metric.

Quality is a quantification of the applicability of a concept to solve the given problem. Quality of a concept is difficult to objectively assess. For the previous study (Berthelsdorf and Stone, 2016), a rubric was created to categorize the quality of the ideas generated. Unfortunately, as there are multiple dimensions of quality, a comprehensive quality rubric is difficult to create: Kudrowitz and Wallace (2013) mention usefulness, relevance, appropriateness, novelty, clarity, workability, and feasibility. The rubric used in this research (see Table 3.1) is intended to rate each

concept along the dimensions of relevance, possibility, specificity, and level of detail. This is averaged over an individual's concepts, and then averaged over the team to find the team quality metric.

Table 3.1. The rubric used to assess the quality of a generated concept.

Score	Level	Detail	Example (sample problem: get someone to do a task)
0	Irrelevant to the problem		Take a nap
1	Not a possible solution		Time travel and do it last week
2	Valid but nonspecific solution	Low	Bribe with food
3		High	Buy lunch Friday
4	Specific valid solution	Low	Buy Pizza
5		Medium	Buy pizza from Dominos
6		High	Buy a large pepperoni pizza from Dominos at noon Friday

Novelty and Variety are measures of the uniqueness of an individual solution. Novelty was assessed by combining similar concepts into bins (e.g. vehicles) and sub-bins (e.g. airplanes and automobiles). A single researcher binned all the concepts, attempting to keep a consistent level of detail of sub-bins between the responses to the design prompts. The number of items in each bin (including sub-bins) was used to determine the novelty of each item in the bin using equation 1 (Chan et al., 2011).

$$Novelty = \frac{(C_t - C_b)}{C_t} \times 10 \quad (1)$$

Where $C_t =$ the total number of concepts generated for a design prompt, and $C_b =$ the number of items in the same bin as an idea (including sub-bins).

Variety is a measure of how different the concepts are within a group of responses to a design prompt. This was calculated as the average novelty of a person's concepts. The resulting

variety was averaged over an individual's concepts, and then averaged over the team to find the team variety metric.

Team Personality

In relationship to personality considerations at the team level, research has typically focused on team formation to achieve a diverse personality profile (Jensen et al., 2000; Wilde and Kim, 2007; Wilde, 2009). Little attention has been given to any potential relationship between team personality and concept generation techniques that are best suited to the team makeup to increase productivity.

Methodology

Four ideation methods – two group and two individual – were tested on a population of mechanical engineering students to determine if a relationship between the team personality make-up and an ideation method existed. Particularly, the effort intended to suss out any relationships that led to higher team productivity as measured by creativity metrics. The group ideation methods were completed in teams of three or four students and were compared against the aggregate performance of the individual members of the team using individual versions of the methods.

The population of this study consisted of the students in a junior-level mechanical engineering design course at Oregon State University. 94 students each took a 70 question MBTI preference sorter (most of them were sorted into SJ, particularly ISTJ, as shown in Table 3.2), and 90 of the students voluntarily chose to participate in at least one ideation session. The course was split into four lab sections, and within each section MBTI information was used to put the students into 3 to 4 person teams for their class project. These same teams were then used for the team ideation methods. As the research was to take place during the scheduled class, the ideation sessions were each limited to 15 minutes; this included explanation of the ideation method, presentation of the design prompt, and 10 minutes of ideation, after which the students indicated whether they wished their data to be used for the study, and their results were collected.

As the population for this study consisted of student engineers, it is not surprising that the population leaned heavily toward SJs in general, and ISTJs in particular. Unfortunately, the sparseness of the data for personality types N and P means that any conclusions drawn for those

personality axes from this dataset would have been less well founded, so those axes are not considered here.

As there were four lab sections, four ideation methods were used:

- individual brainstorming (I-BS),
- group brainstorming (G-BS),
- individual mind mapping (I-MM), and
- group mind mapping (G-MM).

To minimize confounding factors, we decided that each week a different design prompt would be given, and each of the four lab sections would complete a session using a different ideation method. All four ideation methods were used for each design prompt, allowing external confounding factors (such as scheduled events: following one session, the participants were giving a presentation, and some chose to spend some session time reviewing their notes rather than ideating) to be combined with the confounding factor of using different design prompts.

Four design prompts were created for this study. Although reusing the same prompt for all ideation methods for all participants allows the most direct comparisons between these methods, having an individual see the same prompt multiple times would introduce learning effects. In order to mitigate learning effects while still maintaining a valid basis for comparison, we used four different design prompts that are roughly comparable in scope and specificity. These prompts were designed to be similar enough to invite meaningful comparisons, while different enough to mitigate learning effects.

The list that follows consists of the design prompts and some concepts that were generated, including a) a common response, b) an unusual response, and c) a rare response.

5. Generate concepts that will allow zoo-goers to interact with zoo animals.
    a. Feeding the animals
    b. Learn animal calls
    c. Put on a guard dog suit and pay to get mauled by a tiger/lion
6. Generate concepts that will bring supplies to remote areas.
    a. Airplane
    b. Submarine
    c. Trained turtle with supplies strapped to shell

7. Generate concepts that will help a farmer gather his crops.
    a. Tractor
    b. Autonomous crop-picking robots
    c. Ninja cats steal diamonds to allow farmers to buy new equipment
8. Generate concepts that improve the experience of travelling as a passenger.
    a. Food
    b. Xbox/PS4 in vehicle
    c. Lots of puppies on board to play with

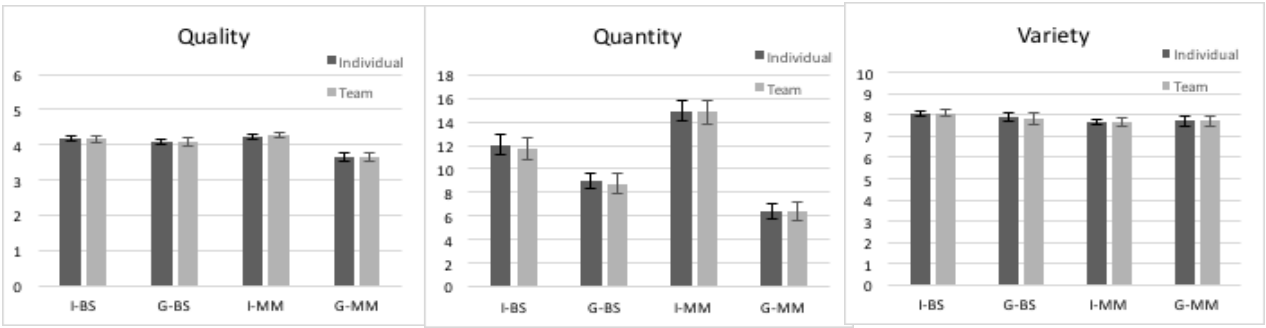

Figure 3.2: Quality, Quantity, and Variety results for individuals and teams

Table 3.2. The number of participants sorted into each MBTI type.

		Sensing (S)		**Intuition (N)**	
		Feeling (F)	**Thinking (T)**	**Feeling (F)**	**Thinking (T)**
Extraversion (E)	**Judging (J)**	ESFJ 10	ESTJ 9	ENFJ 1	ENTJ 3
	Perceiving (P)	ESFP 2	ESTP 0	ENFP 1	ENTP 0
Introversion (I)	**Judging (J)**	ISFJ 12	ISTJ 37	INFJ 1	INTJ 2
	Perceiving (P)	ISFP 4	ISTP 4	INFP 2	INTP 2

Analysis

In this paper, we examine the data for emergent team (or group) personality behaviors. As previously reported (Berthelsdorf et al., 2016), individual preferences for ideation techniques correlated with MBTI personality preferences. The key question here is if a team has an aggregate personality that is determined by its membership and if the team personality prefers certain ideation methods.

Overall Team Averages vs. Summed Individuals

In Fig. 1, individual and team ideation responses are compared for the ideation methods across the entire population. For the two individual methods, the experimental method allows the group results to be parsed for individual contribution so that a direct comparison can be made. For the two group methods, individual ideation results are aggregated into the same composition as the corresponding team so that a direct comparison can be made. The results show that there is no significant difference between the individual and group quality, quantity, and variety measures when converted for direct comparison. Stated a different way, the overall group performance tends to be simply the composition of the individual efforts.

Average Team Personality

A team, composed of individuals each with their own personality, has a personality of its own. In this case, we consider the team to take on a personality that is the composite of its members – in effect, the average personality of the individuals. We postulate that the average team personality should be as close to neutral as possible, i.e., strong extroverts are countered by strong introverts. Ideally, this would indicate that all personality perspectives are represented in the team.

In Figures 2.2-2.7, we look at how teams' personalities impact ideation methods across the three creativity metrics. Given the population observed in this research, there are two personality dimensions that have significant distribution: the Extraversion-Introversion and Feeling-Thinking dimensions. In Figures 2.2 through 2.7, the horizontal axis value of 0 equals either extraversion (E) or feeling (F) and the value of 1 equals introversion (I) or thinking (T). A 'balanced' or neutral team would have a value near 0.5 on either scale.

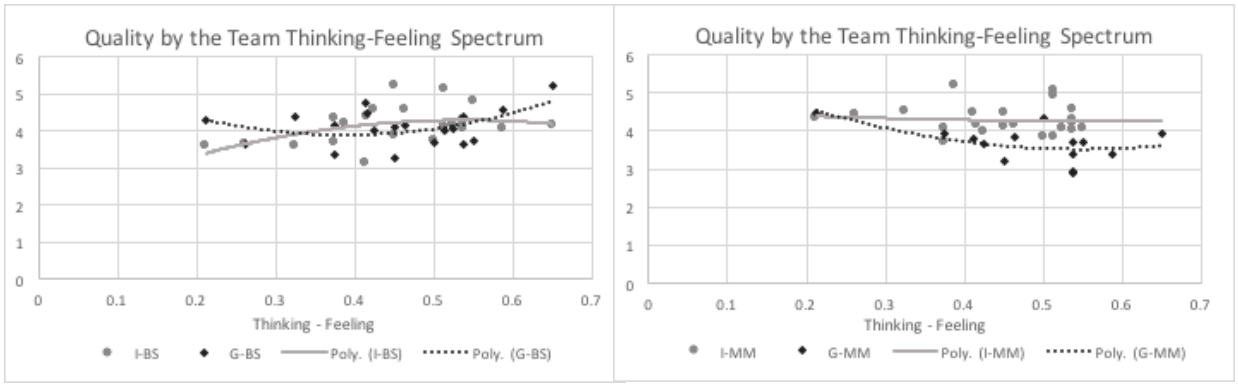

Figure 3.2: Quality on the Thinking-Feeling Spectrum

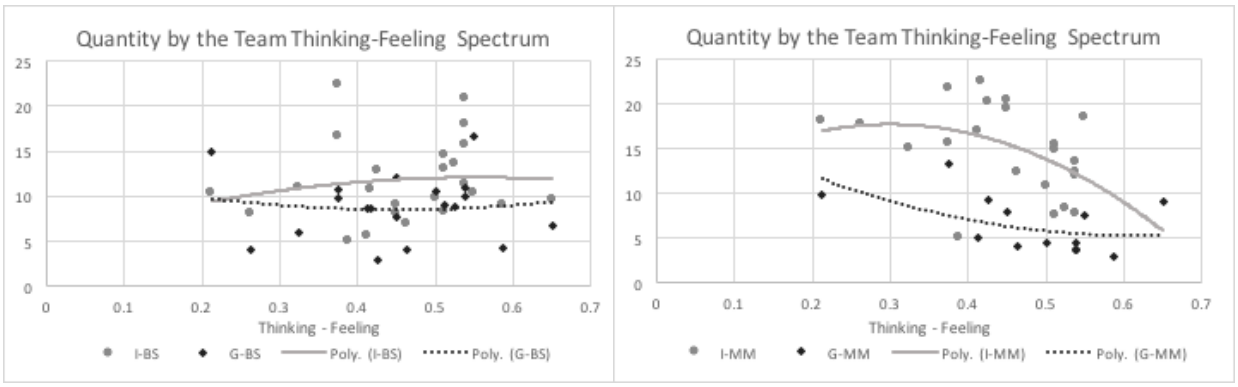

Figure 3.3: Quantity on the Thinking-Feeling Spectrum

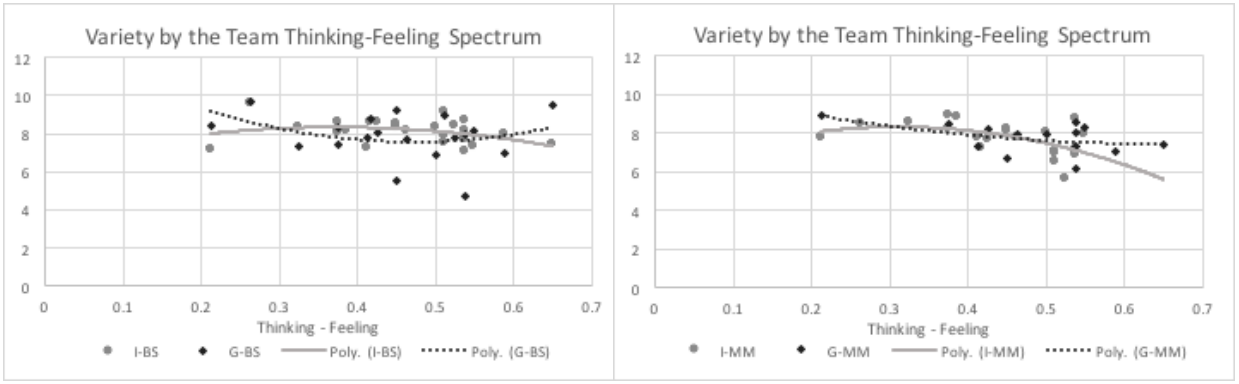

Figure 3.4: Variety on the Thinking-Feeling Spectrum

Quality: In the E-I dimension, teams using G-MM exhibit a maximum quality value near the neutral location, though it is still slightly lower than the composition of the I-MM team while both I-BS and G-BS results are largely independent of team personality. In the F-T dimension, neutral teams benefit most if members individually perform brain storming and/or mind mapping and then aggregate the results. In cases of aggregating the results of individual methods, however, there will almost certainly be some overlap.

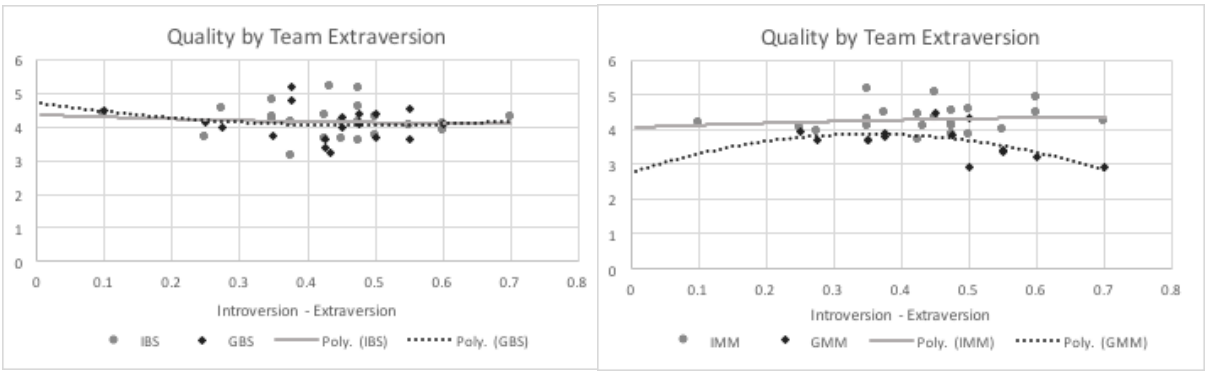

Figure 3.5: Quality by team extraversion

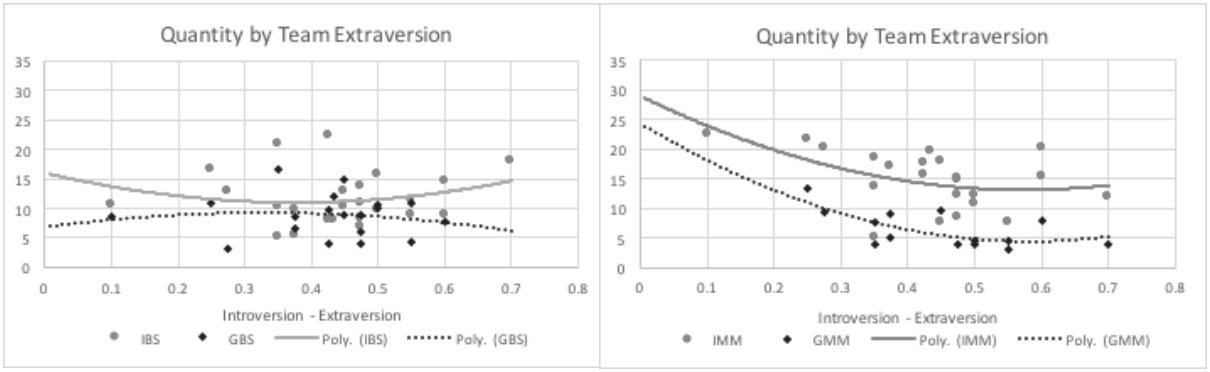

Figure 3.6: Quantity by team extraversion

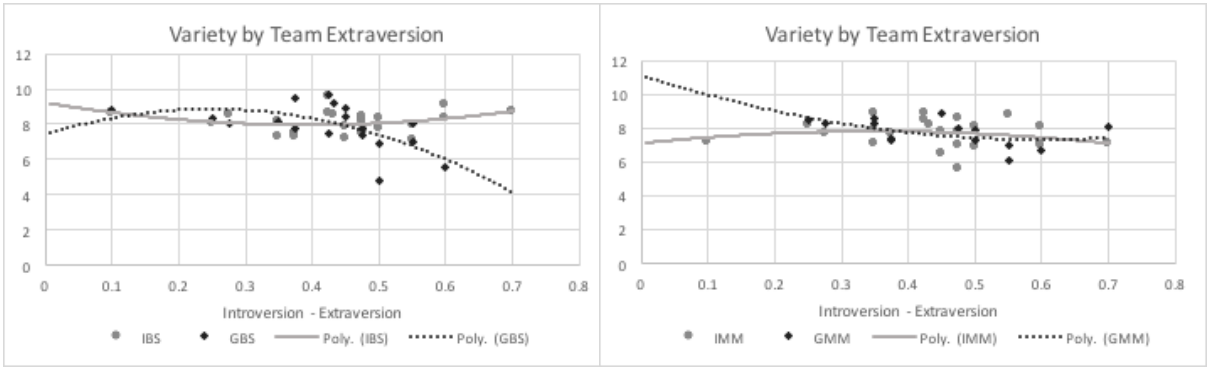

Figure 3.7: Variety by team extraversion

Quantity: In the E-I dimension, neutral teams generate more concepts when using G-BS (though teams biased toward either end of the spectrum generate more concepts by I-BS and then aggregating the results). For the F-T dimension, neutral teams can use either I-BS or I-MM and then aggregate the results to achieve maximum concept quantity.

Variety: In the E-I dimension, G-BS out-performs other methods in the near neutral region for variety. Considering the F-T dimension, I-BS with aggregation offers the best variety result for a neutral team.

Analysis summary: G-BS (for variety and quantity) and G-MM (for quality) do perform better for E-I neutral teams across the three metrics. However, in cases of a team biased toward either end of the spectrum, other ideation methods could be used to advantage to increase a given ideation metric.

Variance in Team Personality

Beyond an average team personality, we postulate that the variance within the team personality may have an impact on ideation performance. In general, we expect that higher variance in team personality will lead to better ideation performance (i.e., larger quantity of ideas, higher quality and larger variety measure of the ideas).

Team MBTI variance was calculated by summing the variance of each MBTI dimension (E-I, S-N, T-F, and J-P) across all team members. As before, individual versions of the brainstorm and mind mapping ideation methods are aggregated to match the composition of the formed teams to provide a comparison to the group versions. On Figures 3.8-3.10 the individual and group ideation metrics for each team are plotted vs. the variance of the team for the brainstorm and mind map ideation methods. Trend lines are overlaid on the same plot.

Quality: For both methods, the individual versions of the methods trend down as variance increases, but the group versions of the methods both trend up. This indicates that even as a team personality becomes more diverse, the act of ideating in a group setting increases the quality of concepts.

Quantity: G-BS trends downward even as I-BS shows a slight positive trend. In this instance, team diversity appears to negatively impact concept quantity. For both versions of mind mapping, the trend is increased quantity with increasing personality variance.

Variety: G-BS trends slightly upward, while the other variations are essentially neutral to personality variance.

Analysis: The more diverse a team's personalities, the better quality results they produce, especially in G-BS, but this comes at the expense of quantity. More diverse teams produce the

highest quantity when using individual methods, particularly I-MM. G-BS may also have a slight variation benefit for highly diverse teams.

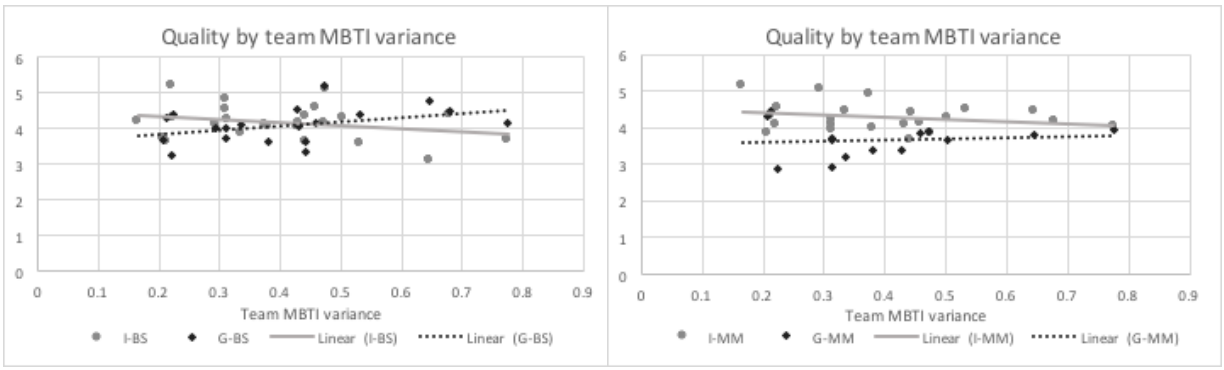

Figure 3.8: Quality as a function of team MBTI variance

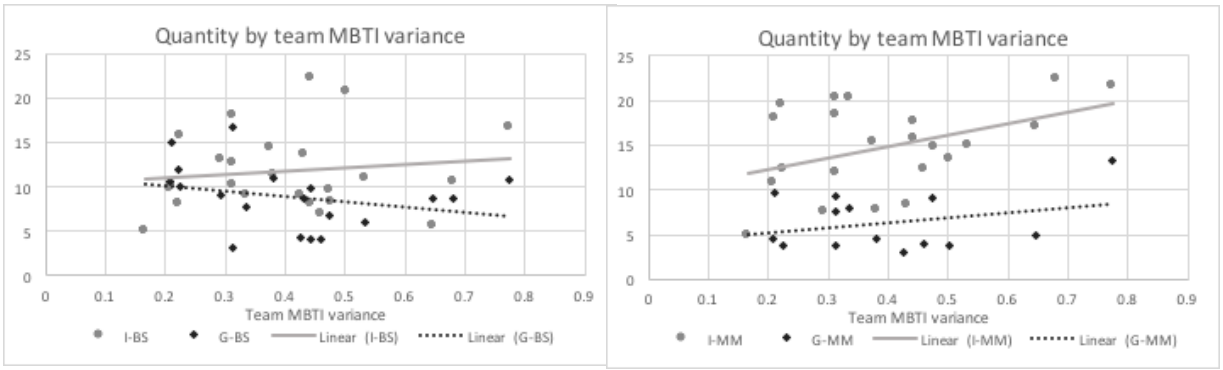

Figure 3.9: Quantity as a function of team MBTI variance

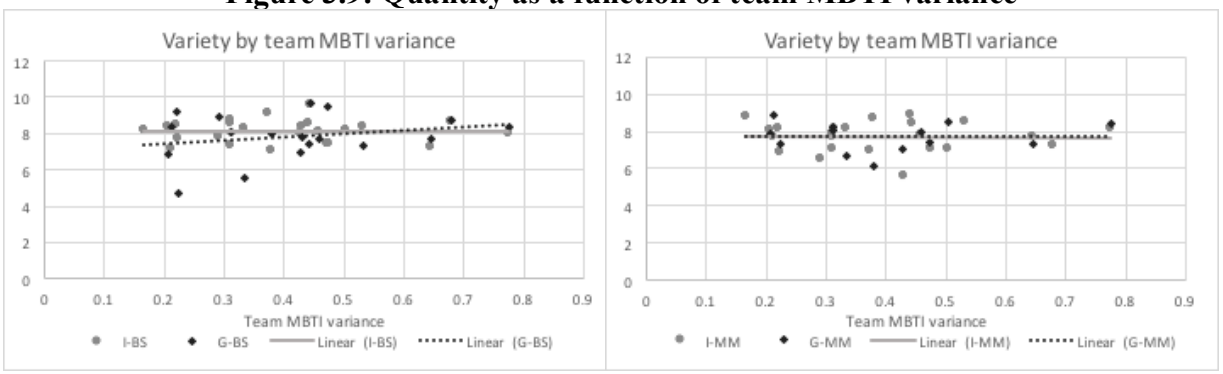

Figure 3.10: Variety as a function of team MBTI variance

Conclusions

Although in several cases, such as using mind-mapping when the metric is quantity, results can be improved by aggregating individual methods rather than using team methods, it must be mentioned that this will almost certainly produce overlapping ideas.

Thinking-Feeling spectrum: By all three metrics, when using a team method, a team heavily biased toward either end of the spectrum will likely be more creative.

Introversion-Extraversion spectrum: When using a team ideation method, a neutral team will likely produce a higher quantity and variety of ideas when using G-BS, but will produce more quality when using G-MM.

Team Variance: When using team methods, a team with a high variance is likely to produce higher quality results. When using G-BS, a high variance team will produce more variety. When using G-MM, a high variance team will produce a higher quantity of ideas.

As statistical testing has not yet been performed, the results of this study cannot be considered definitive.

Future work

In future work, it would be most useful to perform statistical testing to determine the validity of these results, and to increase the sample size, especially of ideators with personalities that were under sampled in this study. There are also many ideation methods that this study did not investigate. Finally, there is an opportunity to examine the effects of personality while using multiple methods in succession.

GENERAL CONCLUSION

This research verified the prior research of Choo et al. (2014), and extended the research by considering aggregate team personality as well.

In general, there is evidence to support that certain personality types tend to achieve better results with certain ideation methods. Further, teams who know their aggregate personality type can tailor the methods they use to increase the likelihood that they will end up with more creative results. Additionally, a team with a high variance is likely to produce higher quality results, and can choose a method to also produce more variety or a higher quantity of ideas.

As the conclusions are based on averages, this should not be considered definitive. Individuals vary, and personal preference or familiarity with the methods or within the team may greatly affect the results.

Without considering personality, I-MM produces the highest quantity of ideas, and G-MM produces the lowest quality and quantity. ETs produce higher quality than EFs when using G-MM, while EFs produce higher quantity than either ETs or Its when using I-BS.

On the team Thinking-Feeling spectrum, teams falling near the center will produce better results using individual methods, while teams falling heavily toward either Thinking or Feeling will produce better results using group methods. This appears to be true for all metrics and methods studied.

On the team Extraversion-Introversion spectrum, the results are more varied. Quality results suggest that teams that are very Introverted should use G-BS, while other teams should use I-MM. Quantity results suggest that heavily Extraverted teams should use I-BS, while other teams should use I-MM, as individual methods outperform team methods. Variety results are more varied, with heavily Introverted teams suggested to use G-MM, more mildly Introverted teams suggested to use G-BS, and Extraverted teams suggested to use I-BS.

Team variance results suggest that when quality is the metric, low variance teams should use I-MM while high variance teams should use G-BS. For Quantity, most teams should use I-MM, but very low variance teams should use G-BS. For Variety, high variance teams should probably use G-BS, while low variance teams should avoid it.

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