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CREATIVITY IN ENGINEERING: SYSTEMS THINKING APPROACH TO IMPROVE UNDERSTANDING

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CREATIVITY IN ENGINEERING: SYSTEMS THINKING APPROACH TO IMPROVE UNDERSTANDING

A DISSERTATION APPROVED FOR THE
SCHOOL OF INDUSTRIAL AND SYSTEMS ENGINEERING

BY THE COMMITTEE CONSISTING OF

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Dr. Theodore Trafalis • Dr. Hairong Song • Dr. Pedro Huebner Dos Reis

DEDICATION

to the CREATORS, with an apology

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There are countless people to whom I would like to express my gratitude; a few of them I interacted with personally, and many I learned and benefited from their work through a diverse set of media. Although I would like to thank everyone, I do not see a space enough to do so. Given this space limitation, I will only explicitly mention seven groups of people who played a significant role in shaping my personality and the work I am presenting here.

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The last but indeed not the least group of people I would like to thank are those I do not know personally but benefited from their work in one way or another. This group is enormous and will require ample space if I would enumerate all the names (or nicknames); instead I will shout THANK YOU.

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NOTICE

This dissertation was written with the inclusion notion in mind, and it should be used so. The whole purpose was to help people, especially students, recognize (a) the different creativity types built into them, (b) the level of each creativity type that they are currently possessing and standing on, and (c) the diverse ways to push themselves to the next level of each creativity type they wish to work on. Similarly, I would love to see educators use this work to recognize (a) the distinct types of creativity their pupils have, (b) at what level each pupil is currently standing, and (c) to what level each pupil needs to reach. Notice that I used the singular form "pupil" and not the plural form "pupils" to signal that no matter what we do as educators, our pupils will be different, which is a strength, not a weakness. Hence, this dissertation represents an invitation for educators to work toward more tailored, personalized education and an invitation for designers and researchers to work toward more personalized designs, solutions, and experiences[1].

On the other hand, it would be disappointing to see this work being utilized to exclude people from specific programs or be used as an acceptance criterion for specific jobs, as what happened with the intelligence quotient (IQ) test. IQ was initially used to help educators figure out the areas their pupils are experiencing difficulties with. Still, later, unfortunately, it was used to classify people and as an exclusion criterion[2].

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[1] Interested readers shall consulate the monograph titled *Assessing Creativity: A Guide for Educators* by Treffinger, Young, Selby, and Shepardson (2002) for a detailed discussion on how to recognize and assess creativity in students and help them reach their creative potential.

[2] See ("Why IQ is not the same as intelligence," 2020) for a short overview of the history of IQ.

ABSTRACT

On the surface, creativity seems to be an attainable, easy-to-master construct. However, when diving into the literature, the observer will realize that creativity is a complex, multifaceted, highly debatable phenomenon with many definitions, models, and factors attached to it. Given the complexity and the multi-disciplinary nature of creativity, this dissertation took the systems thinking approach to organize its associated landscape and confirm the effect of some factors on engineers. The mission was accomplished by *first* proposing a data-driven definition for creativity based on the analysis of 166 definitions. *Second*, a classification of the vast number of models describing creativity was proposed based on the analysis of tens of creativity related papers. The classification resulted in five categories: Level Models, Thematic Models, Process Models, Mental Models, and Ecological Models. *Third*, a nested model for the five creativity levels: mini-c creativity, little-c creativity, ed-c creativity, Pro-c creativity, and Big-C creativity was proposed based on an extended analysis of four creativity level models: 2C Model, 3C Model, 4C Model, and 5C Model. *Fourth*, an enhanced thematic model for the seven strands of

creativity: person, process, product, press, measure, persuasion, and potential was proposed based on the analysis of five creativity thematic models: 3PM Model, Rhodes 4P Model, Simonton 4P Model, 5P Model, and 6P Model. *Fifth*, a simplified process model for creativity consisting of three interconnected steps: problem understanding, divergent thinking and convergent thinking was proposed based on an extended analysis of two creativity process models: Wallas Model and Osborn-Parnes Creative Problem-Solving Model and an overall analysis of six other models. *Sixth*, a classification of the vast number of factors affecting creativity was proposed based on the analysis of tens of creativity related papers. The classification resulted in three categories: personal characteristics, environmental characteristics, and approaches and tools. *Seventh*, an ecological model for creativity based on the classification suggested for creativity models as well as the classification suggested for creativity factors was proposed. *Eighth*, the relationship between a set of personal characteristics (biological factors, knowledge and experience, personality, creative self-efficacy, and creative potential), task engagement, and creative performance was studied to confirm their effects in the field of engineering. *Ninth*, the effect of near and far cues on the creative performance of engineers was investigated both behaviorally and neurologically and no statistically significant differences were detected.

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
AUT	Alternative Use(s)/Usage Task
BFAS	Big Five Aspect Scales
BFI	Big Five Inventory
CFC	Componential Framework of Creativity
CIMC	Csikszentmihalyi Integrated Model of Creativity
CMC	Creative Metacognition
CPS	Creative Personality Scale
CSB	Creative Self-belief
CSC	Creative Self-concept
CSE	Creative Self-efficacy
EEG	Electroencephalography
electrode site – C	Central
electrode site – F	Frontal
electrode site – Fp	Frontal pole
electrode site – O	Occipital
electrode site – T	Temporal
electrode site – z	Zero
ERP component – N	Negative
ERP component – P	Positive

ERPs	Event-Related Potentials
fMRI	functional Magnetic Resonance Imaging
GEO	Game Engagement Questionnaire
GLM	Generalized Linear Model
GUI	Graphical User Interface
HLM	Hierarchical Linear Model
IB	Ideation Behavior
ICC	Intra-class Correlation
IEQ	Immersive Experience Questionnaire
IPIP	International Personality Item Pool
IQ	Intelligence Quotient
IRR	Inter-rater Reliability
LCC	Little-C Creativity
LCD	Louvain Community Detection
LDA	Latent Dirichlet Allocation
LPON Component	Left-Parietal Old-New Component
MFON Component	Midfrontal Old-New Component
ms	milliseconds
ONPP	Old-New Probe Paradigm
PCL	Presentation Control Language
PET	Positron Emission Tomography
PRISMA guidelines	Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines
RIBS-S	Runco Ideation Behavior Scale-Short
RQ	Research Question
SDL	Scenario Description Language

TDF	Term-Document Frequency
TTCT	Torrance Tests of Creative Thinking
μV	microvolts

1
INTRODUCTION & DISSERTATION STRUCTURE

"You will never come up with the right answer if you ask the wrong question."

—Robert J. Sternberg

1.1 Overview

Creativity is a subject surrounded by many misconceptions: some people confine it only to art and artists[3] while others attribute it to a mysterious spiritual power, yet some see

[3] The art can take different forms: *visual art* such as drawing, painting, and collage; *performance art* such as theater and dance; *written art* such as poetry, pose, fiction, playwriting, and screenwriting; *music and song* production; *film and video* production; and *storytelling*.

it as a gift for the elite. Besides the lack of a deep understanding of the creativity phenomena, these and other misconceptions discouraged many researchers from approaching this field of study despite its increasing importance (Sternberg & Lubart, 1996); more about the importance of creativity will be discussed in Section 1.3. The factors above result in creativity not yet receiving the appropriate attention that it deserves and being an unappreciated subject in the domain of rigorous research (Rhodes, 1961; Sternberg & Lubart, 1996). Since Joy P. Guilford's call to focus on creativity research in 1949, no significant shift has been observed during his presidential address to the American Psychological Association (Sternberg & Lubart, 1996). The percentage of creativity research in the *Psychological Abstracts* periodical when Guilford gave his speech was less than 0.2%, only 186 entries out of the 121,000 entries. The percentage increased to only around 0.5% when later searching the same periodical (Sternberg & Lubart, 1996).

Besides the many misconceptions surrounding creativity, many factors shape the creativity research field as to how it appears right now as a disastrous, messy field of fragmented research (Glăveanu, 2014; Hennessey & Amabile, 2010; Kaufmann, 2003b; Kharkhurin, 2015; Simonton, 2018b). One of the major causes for the rise of these islands of research is the differences in the fundamental treatments and understandings of creativity, as discussed in detail in Section 1.2. This segregation in research made those who belong to one camp unaware of, in the best-case scenario, or rejecting, in the worst-case scenario, the work of other researchers in other camps (Glăveanu, 2014; Hennessey & Amabile, 2010). This situation reminds us of the intellectual debate between the proponents of the subjective measures and the proponents of the objective measures (see Johnson and Onwuegbuzie (2004); Onwuegbuzie and Leech (2005) for an interesting discussion). Each camp believes that the way they approach creativity is the right way and uses a fundamentally distinct set of methods to understand creativity. However, the truth most probably lies in the middle—a combination of all the views, not only in creativity research but also in general, is usually the best approach to understanding creativity. This middle stand is the approach adopted throughout this dissertation, i.e., when possible, all views will be considered when answering the posed research questions. Hence, an outline of the main camps currently exist in creativity research will be provided in Section 1.2 before handling any other topic. The outline will give the researcher a practical framework to distinguish between the different research approaches currently available in the creativity literature. Hence, any conflicting results that one may encounter could be due to the different approaches employed to study creativity.

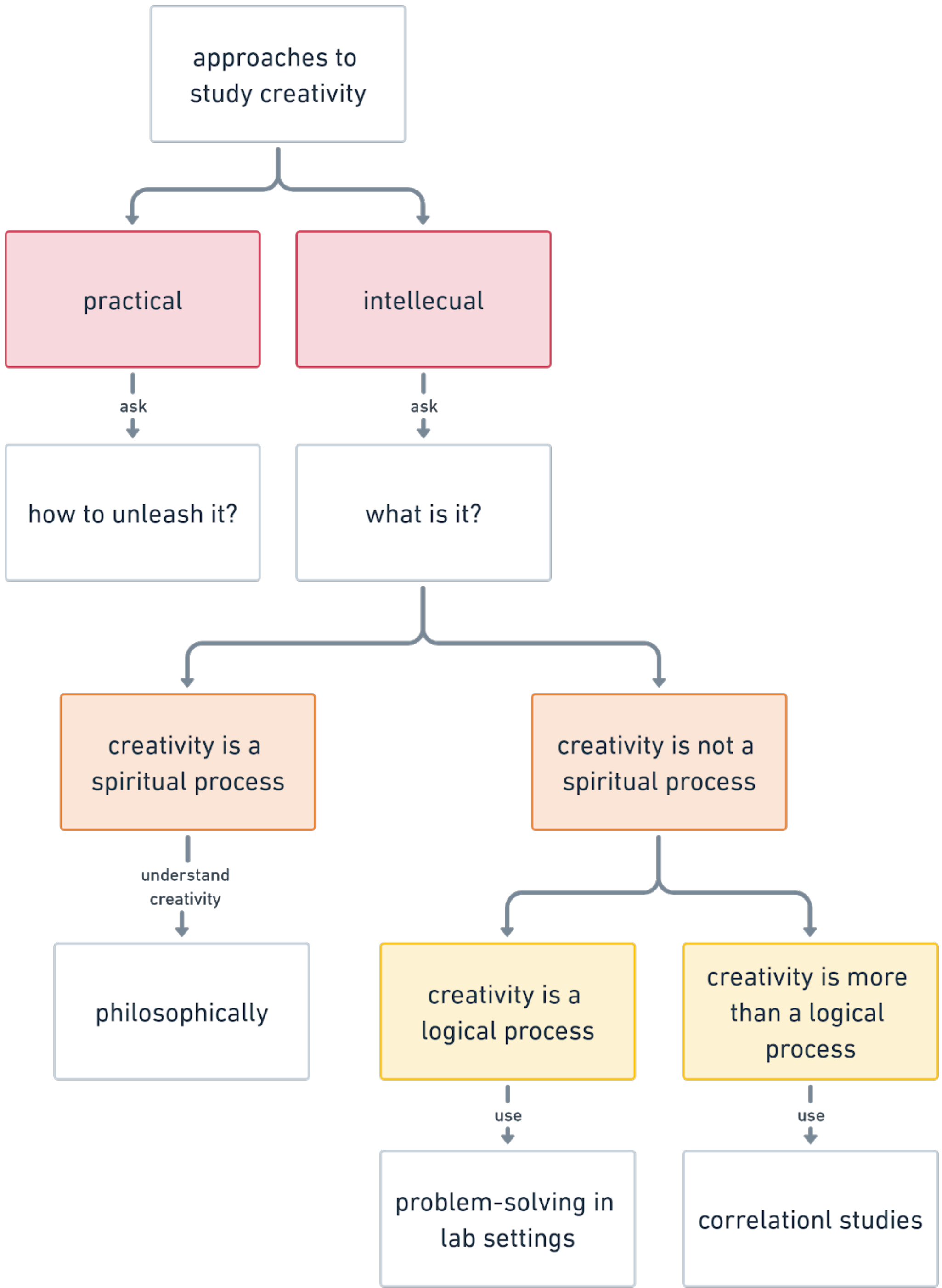

Figure 1: An outline of the different approaches taken by researchers to study creativity. Each pair of colored boxes represent a fundamental split in the approach taken to study creativity, while the white boxes give more details about the approach from which the directed arrow is starting.

1.2 Approaches to Study Creativity

As mentioned in Section 1.1, one of the major causes of the divide in creativity research is the fundamental differences in the way researchers approach and study creativity. Most of the work done on creativity can be divided into two mainstreams. The first mainstream concerns with the practical application of creativity, i.e., making people more creative and unleashing people's creativity, without paying a great deal of attention to the validation process. The other mainstream of researchers focuses on understanding creativity as a phenomenon without focusing on the application side.

Those researchers who pay more attention to creativity as a phenomenon can be further classified into two groups: (a) those who see it as a spiritual process and try to understand it philosophically and (b) those who believe otherwise and hence try to pin it methodologically. Furthermore, those who approach creativity methodologically can be classified into two groups: (i) those who see creativity as a logical process and hence use problem-solving in a laboratory setting as a proxy to understand it and (ii) those who believe that creativity is more than a logical process and hence use correlational studies (Kharkhurin, 2015; Murdock & Puccio, 1993; Sternberg & Lubart, 1996). Figure 1 shows a visual depiction of the different approaches used to study creativity.

1.3 Importance of Creativity

Creativity is the most essential skill in the 21st century (Florida, 2012) or one of the most essential ones (Charyton, 2014; D. H. Cropley & Patston, 2019; Han, Shi, Chen, & Childs, 2018; T.-C. Huang, 2019; Kao, Chiang, & Sun, 2017; Peterson & Harrison, 2005; Simonton, 2000; Stephanidis, Salvendy, Antona, Chen, Dong, Duffy, Fang, Fidopiastis, Fragomeni, Fu, Guo, Harris, Ioannou, Jeong, Konomi, Kromker, Kurosu, Lewis, Marcus, Meiselwitz, Moallem, Mori, Nah, Ntoa, Rau, Schmorrow, Siau, Streitz, Wang, Yamamoto, Zaphiris, & Zhou, 2019). It is a desired quality for admission to graduate school (Enright & Gitomer, 1989; Kaufman & Beghetto, 2009), and the National Science Foundation considers it competitive merit when reviewing grant applications (Kaufman & Beghetto, 2009; Lane, 1997). It is also a necessity for innovation and prosperity and a needed skill for survival and solving everyday problems (Charyton, 2014). In engineering design, creativity is a necessity, not an accessory, to enrich people's lives and to benefit humankind (Charyton, 2014; Charyton & Merrill, 2009; Howard, Culley, & Dekoninck, 2007). As Bornet (2009) put it, according to M. Tang (2017)[4], we are moving from the *Information Age* to the *Creativity Age* where the focus is on *generating ideas* and not *producing things* (R. K. Sawyer, 2012; M. Tang, 2017).

On the research side, Simonton and Lebudaiza (2019) stated that our current time is a *golden age* for creativity research. Similarly, in the industry side, Runco (2011a) reported that (a) 1500 CEOs of corporate and public sectors and (b) public leaders in 60 countries and 33 industries indicated in a 2010 poll by IBM that creativity is the most essential leadership skill.

Academic and industrial societies are also placing a big emphasis on creativity. For example, creativity was declared one of the seven grand challenges in the human-computer interaction discipline (Stephanidis et al., 2019). In its report *The Engineer of 2020: Visions of Engineering in the New Century*, the National Academy of Engineering (2004) considered creativity as "an indispensable quality for engineering" (p. 55). Also, the World Economic Forum (2016) stated in its report *New Vision for Education:*

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[4] The reference to Bornet (2009) in M. Tang (2017) which is "Bornet, R. (2009). *The Creativity Age and the Future of the World.* Retrieved January 31, 2015, from https://creativityage.wikispaces.com/Creativity+Age." was not available when checked on February 24, 2021.

Fostering Social and Emotional Learning through Technology that a "projected 65% of children entering grade school will work in jobs" that will require creativity beside other social and emotional skills (p. 6). Similarly, in its report, *UN Competency Development - A Practical Guide*, the United Nations (2010) listed creativity as a core competence that students should develop. In its Innovative Skills Profile 2.0, The Conference Board of Canada (2021) listed creativity among the top skills, attitudes, and behaviors that individuals need to have to contribute to an organization's innovation performance—"to produce new and improved strategies, capabilities, products, process, and services."

Nations are also emphasizing creativity. The United Kingdom and Australia have explicit support to include creativity in the curriculum, according to Karwowski, Gralewski, Patston, Cropley, and Kaufman (2020). European Union declared 2009 as the *European Year of Creativity and Innovation* to enhance the awareness level of creativity to strengthen social and economic progress (Sharma, 2020). Europe launched *Erasmus+* in 2017 and *Horizon 2020* projects to incorporate creativity and innovation as lifelong learning to foster competitive development of the economy, according to M. Tang (2017). India declared 2010-2020 as the *Decade of Innovation* and established the *National Innovation Council & The Science, Technology and Innovation Policy 2013* to strengthen its innovation ecosystem, according to Ravindra (2014). Singapore launched the three master plans for information and communications technology in education in 1997, according to M. Tang (2017).

1.4 Outline of Dissertation

The dissertation will focus on answering the following main research questions:

- RQ1: What is creativity?
- RQ2: What models of creativity exist?
- RQ3: What factors affect creativity? and
- RQ4: How is creativity different in engineering?

The overall flow of the dissertation is shown in Figure 2. Chapter 2 will address *RQ1: What is* creativity? and will provide a data-driven definition for creativity based on a gap analysis of a set of creativity definitions extracted from the engineering and non-engineering literature. The proposed definition will be based on the collected and analyzed creativity definitions and will also be based on the answers obtained to the other research questions.

Answering *RQ1: What is* creativity? will be through answering the following sub-research questions:

- RQ1.1: What aspects of creativity are being focused on in the engineering literature?
- RQ1.2: What aspects of creativity are being focused on in the generic literature?
- RQ1.3: How is engineering different from generic literature when defining creativity?
- RQ1.4: What aspects of creativity are missing from definitions?
- RQ1.5: Considering the answers to RQ1.1 through RQ1.4 and the answers to RQ2 and RQ3, what an appropriate definition of creativity can be proposed?

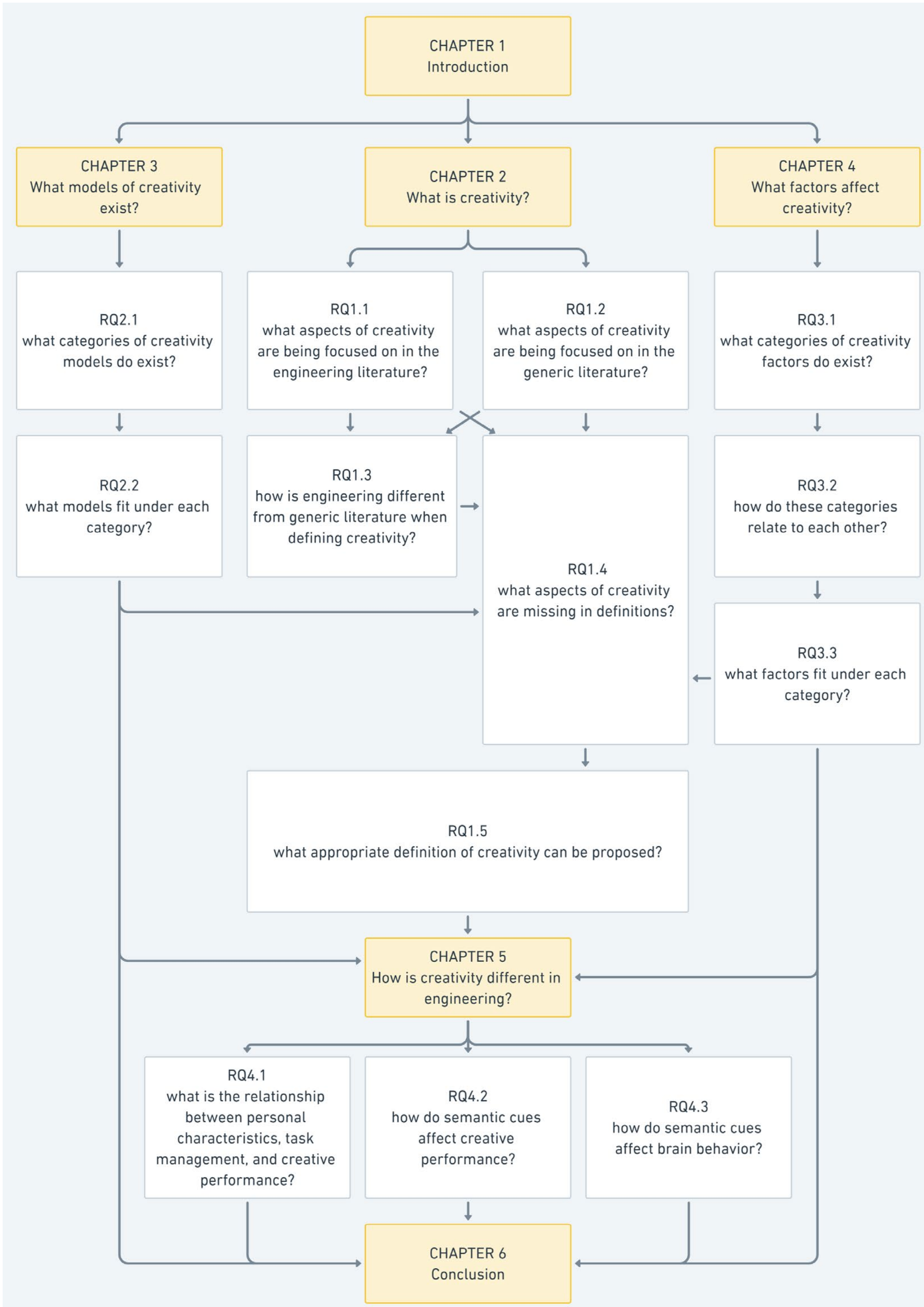

Figure 2: An outline of the chapters (shown in yellow boxes) of the dissertation, the research questions (shown in white boxes) being addressed in each, and the dependency (shown via directed arrows) between the different chapters and research questions.

Chapter 3 will answer *RQ2: What models of creativity* exist? by addressing the following sub-research questions:

- RQ2.1: What categories of creativity models exist?
- RQ2.2: What models fit under each category?

Chapter 4 will be utilized to answer *RQ3: What factors affect* creativity? by addressing the following sub-research questions, similar to the approach used to answer RQ2:

- RQ3.1: What categories of creativity factors exist?
- RQ3.2: How do these categories relate to each other?
- RQ3.3: What factors fit under each category?

While Chapters 2 through 4 aims to clarify creativity research, Chapter 5 focuses on understanding creativity in the engineering context by answering *RQ4: How is creativity different in* engineering? To answer this research question, an experiment is proposed and conducted with engineering students to evaluate the effect of one of the cue factor believed to enhance creativity and assess if the same results transfer to engineering. The chapter also investigates the relationship between creative performance shown by engineering students and a set of personal and environmental factors. Chapter 5 includes a discussion on how engineers process information differently from the general public. Hence, the findings presented in the general literature may have some nuances for engineering. The possible mismatch between the findings in the general creativity literature and the field of engineering represents the focus of the experiment that will be reported in Chapter 5. The chapter will address the following sub-research questions:

- RQ4.1: What is the relationship between (a) personal characteristics: biological factors, knowledge and experience, personality, creative self-efficacy, and creative potential; (b) task engagement; and (c) creative performance?
- RQ4.2: How do semantic cues affect creative performance?
- RQ4.3: How do semantic cues affect brain behavior?

Chapter 6 concludes the dissertation and outlines the future work. Figure 2 presents a graphical depiction of the dissertation structure, what research questions will be answered in each, and the dependencies between the different research questions and chapters.

2
CREATIVITY DEFINITION

"You can't use up creativity. The more you use, the more you have."

—Maya Angelou

2.1 Introduction

Defining creativity is a challenging task. Concepts, in general, are complicated to define (Podsakoff, MacKenzie, & Podsakoff, 2016), and the difficulty substantially increases when defining complex, multifaceted phenomena such as creativity and intelligence (Sternberg & Kaufman, 2018). Like intelligence, there is no single agreed-upon definition for creativity; What is it? What does it mean? How to recognize it? How does it happen?

How to measure it? etc. (Sternberg & Kaufman, 2018). When defining creativity, one common direction is the act that the phenomenon produces as output and list the attributes that such an act needs to possess in order to be considered creative. This approach represents the attributes' direction approach.

Researchers, in general, have utilized generating an attributes list when defining creativity and agree that for an act to be labeled creative, it must possess the *novelty* attribute, also referred to as *originality* or *newness* (Sternberg & Kaufman, 2018). Despite the agreement on the novelty attribute, there is no agreement on what it exactly means and how to operationalize it (Batey, 2012; Batey & Furnham, 2006; Runco & Jaeger, 2012). The second important attribute after novelty that many creativity researchers request to appear in an act to be deemed creative is the *usefulness* attribute. This attribute appears under other names such as *value*, *purpose*, *solving a problem*, and *utility* (Charyton, Jagacinski, & Merrill, 2008; Nickerson, 1998). The goal to include this attribute is to eliminate the novel acts that are "simply absurd" (Dacey & Madaus, 1969, p. 56). Other attributes such as *feasibility*, *compelling*, *aesthetic*, *transformation*, and *adaptiveness* are less agreed upon (Batey, 2012; A. J. Cropley, 2000; Dacey & Madaus, 1969; Puryear & Lamb, 2020; Runco, 2018; Runco & Jaeger, 2012; Simonton, 2018a; Treffinger, 2011; Wallace, 1986; Wolf, 2014). It is worth mentioning that the more number of attributes that get added to the creativity definition, the most restrictive the creativity circle will be, i.e., the less number of acts that can be labeled as creative. This is one of the arguments that researchers raise when trying to produce a definition for creativity (Podsakoff et al., 2016; Runco & Jaeger, 2012).

This chapter takes a data-driven approach, paired with systems thinking (Arnold & Wade, 2015) to develop a comprehensive definition for creativity. The findings to the research questions posed in this chapter and the answers to the research questions posed in the forthcoming chapters will be taken into consideration when proposing the definition.

2.2 Motivation

The decision to seek an adequate definition for creativity was motivated by the argument raised by Rhodes (1961) that the many existing definitions of creativity give the reader the illusion that creativity research is a field of speculation. Many researchers, as a result, avoided approaching the field because of the ambiguity surrounding it (Rhodes, 1961). Hence, providing an adequate definition based on an extended quest on how researchers, who deal with creativity see it, i.e., a data-driven definition, will help convince more researchers to come forward and study creativity further.

2.3 Chapter Outline

The chapter is organized as follows. First, the research questions that ought to be answered are listed in Section 2.4. Second, the methodology used to answer the posed research question is described in Section 2.5. While Section 2.5 will show intermediate results that will yield from some of the steps of employed methodology, Section 2.6 presents the results for the posed research questions and a discussion around them. The chapter ends with a conclusion and a prolog to the next chapter in Section 2.7.

2.4 Research Questions

The main research question that will be answered in this chapter is RQ1: What is creativity? The question will be tackled by answering the following sub-research questions, as also shown in Figure 2:

- RQ1.1: What aspects of creativity are being focused on in the engineering literature?
- RQ1.2: What aspects of creativity are being focused on in the generic literature?
- RQ1.3: How is engineering different from generic literature when defining creativity?
- RQ1.4: What aspects of creativity are missing from definitions?

- RQ1.5: Considering the answers to RQ1.1 through RQ1.4 and the answers to RQ2 and RQ3, what an appropriate definition of creativity can be proposed?

2.5 Methodology

Answering RQ1: What is creativity?, posed in this chapter, will be based on the data-driven approach coupled with the systems thinking methodology (Arnold & Wade, 2015). Figure 3 outlines the process that will be followed to answer the first three sub-research questions. Answering the last two sub-research questions will require, besides the answers obtained for the first three sub-research questions in this chapter, the answers obtained for the posed research questions in Chapters 3 and 4 as outlined in Figure 2.

The process to answer RQ1.1 through RQ1.3 in this chapter starts by building two corpora of creativity definitions, one from the engineering literature and one from the generic literature as detailed in Section 2.5.1 and Section 2.5.2, respectively. After that, the corpora are analyzed using the process outlined in Section 2.5.3. The results of the analysis are presented and discussed in Section 2.6.

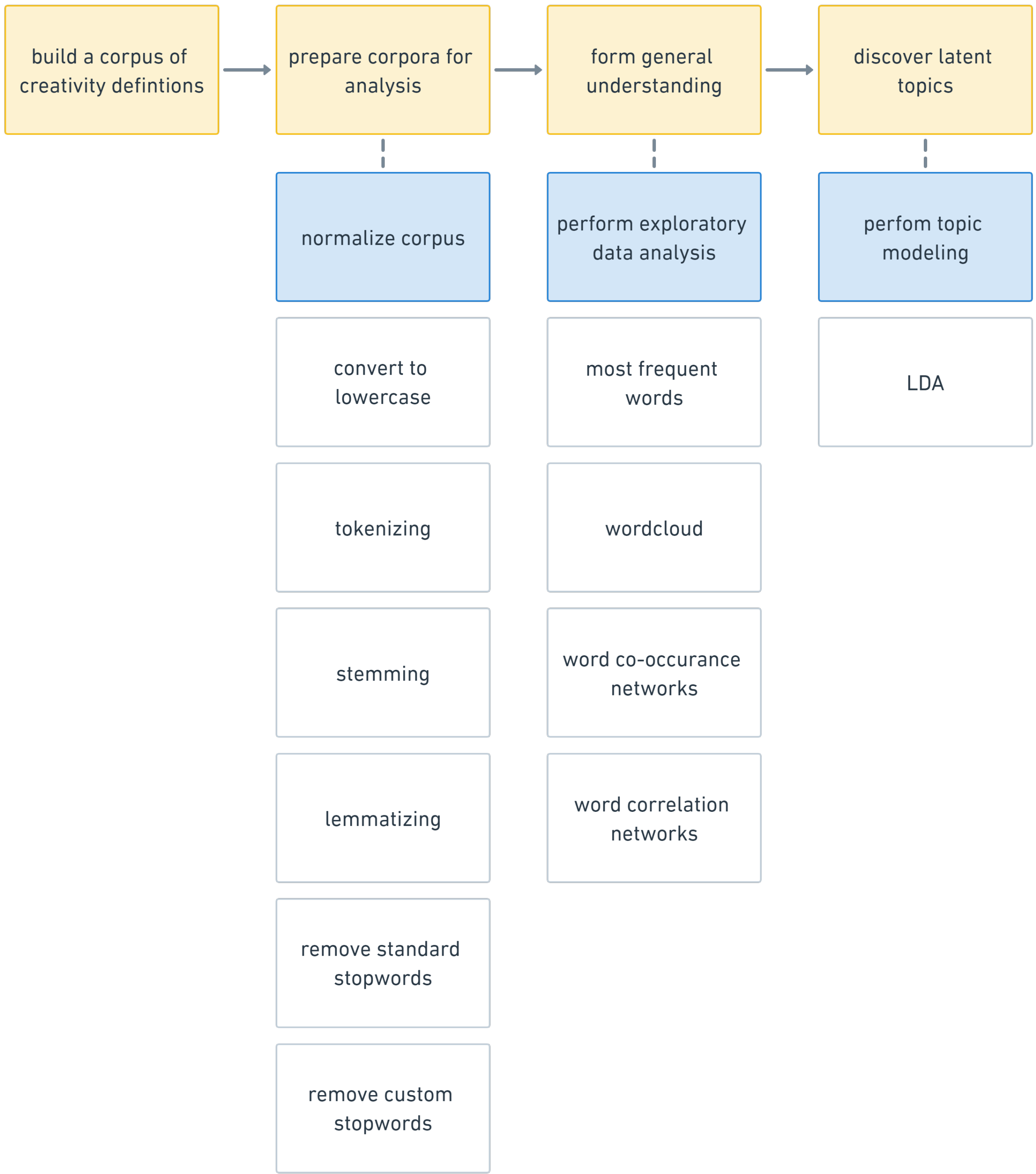

Figure 3: An outline of the process used to answer the first three research questions posed in this chapter, i.e., RQ1.1: What aspects of creativity are being focused on in the engineering literature? RQ1.2: What aspects of creativity are being focused on in the generic literature? and RQ1.3: How is engineering different from generic literature when defining creativity?

2.5.1 Building Engineering Creativity Definition Corpus

This section outlines the steps taken to build a corpus of creativity definitions from the engineering literature. Figure 4 outlines the main steps involved in the process. The first step in the process is the articles searching strategy (Section 2.5.1.1), which answers the question "What articles to consider for inclusion in the search results and what articles to consider excluding from the search results?" The second step in the process is the articles selection strategy (Section 2.5.1.2) which answers the question "Which publications to include in the corpus?" The last step in the process is the data extraction process (Section 2.5.1.3) which answers the question "What information from the publication needs to be saved into the corpus besides the creativity definition proposed/used?"

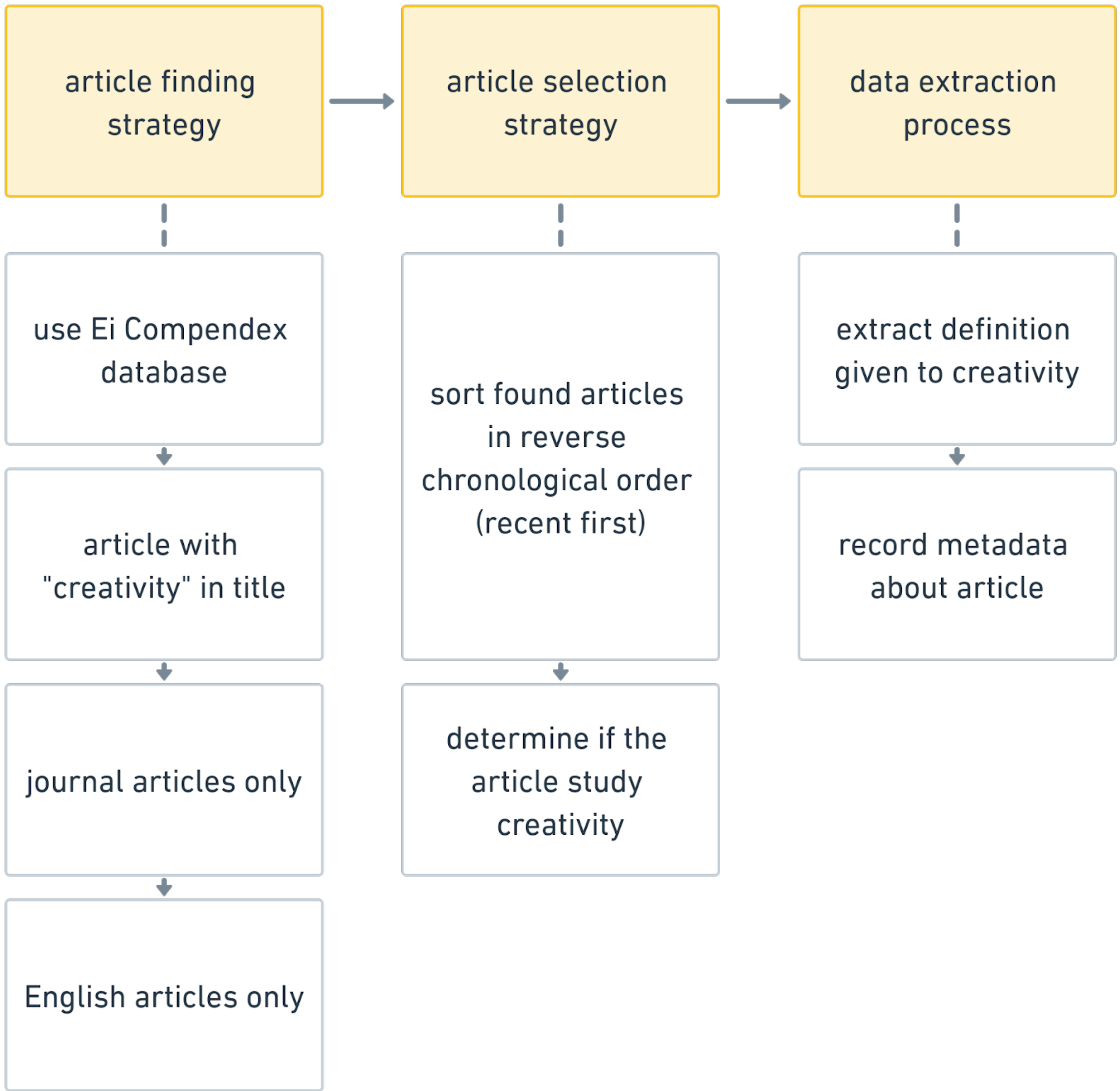

Figure 4: An overview of the steps to build a corpus of creativity definitions from the engineering literature. The yellow highlighted boxes represent the major steps involved in the process while the white boxes represent the sub-steps under each major step

2.5.1.1 Articles Finding Strategy

Ei Compendex Database. Ei Compendex database, accessed via the Engineering Information Village, was used to find peer-reviewed publications in the engineering discipline. According to its publisher, Elsevier[5], the Ei Compendex database is considered "the broadest and most complete engineering literature database available in the world." The search was first performed on April 23rd, 2020, then later updated on August 3rd, 2020, and August 25th, 2020. The search was directed by the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (Moher, Liberati, Tetzlaff, & Altman, 2009).

The process initially started using the keyword "creativity" as a search keyword in the title field. This initial search resulted in 4,066 matches. The results were then restricted to only journal articles, bringing the number of entries to 1,214 articles. After that, the search was further restricted to those written in the English language. This step did not change the number of entries obtained in the previous step, i.e., the number of matching articles remains 1,214. The expert search expression for each step of the process

[5] www.elsevier.com/solutions/engineering-village/content/compendex

Table 1: The expert search expressions performed on Ei Compendex database with the number of results obtained up to August 25th, 2020, during the building process of the creativity definition corpus from the engineering literature.

Search Step	**Expert Search Expression**	**Number of Results Obtained**
articles with the word "creativity" in the title	(("creativity") WN TI)	4,006
restricting the search to journal articles only	(((("creativity") WN TI)) AND ({ja} WN DT))	1,214
restricting the search to articles written in English language	((((("creativity") WN TI)) AND ({ja} WN DT)) AND ({english} WN LA))	1,214

is shown in Table 1, along with the number of articles matching each step of the process when the search was performed on August 25th, 2020.

Figure 5 to Figure 8 is used to show the distribution of the 1,214 obtained articles based on year of publication, controlled vocabulary, classification code, and source title according to the metadata provided by the Ei Compendex database.

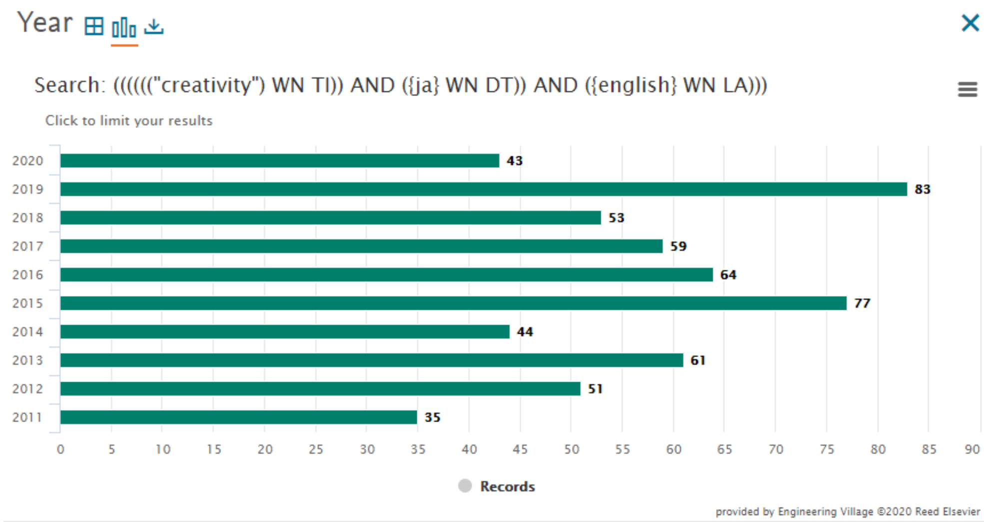

Figure 5: The distribution of the years of publication of the 1,214 articles obtained during the last step of searching Ei Compendex database.

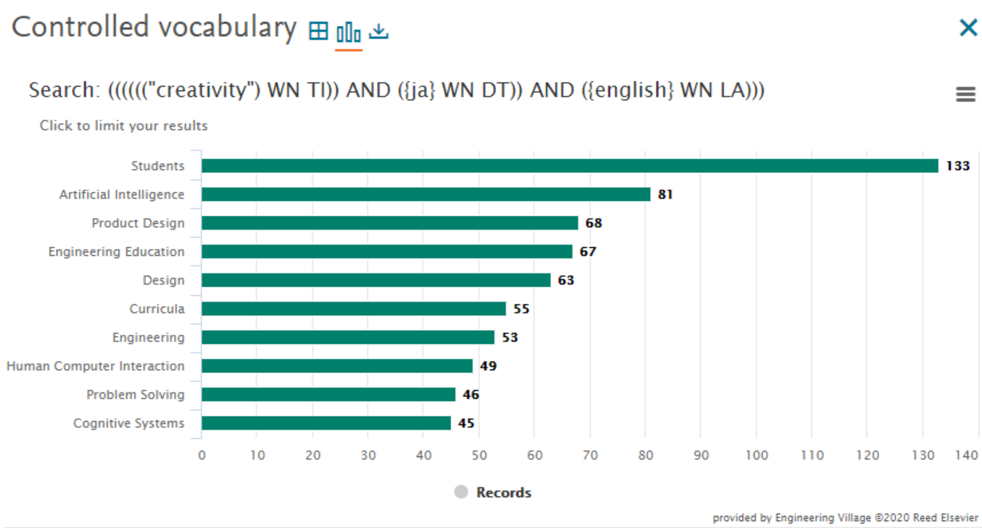

Figure 6: The distribution of the controlled vocabulary of the 1,214 articles obtained during the last step while searching for articles in Ei Compendex database.

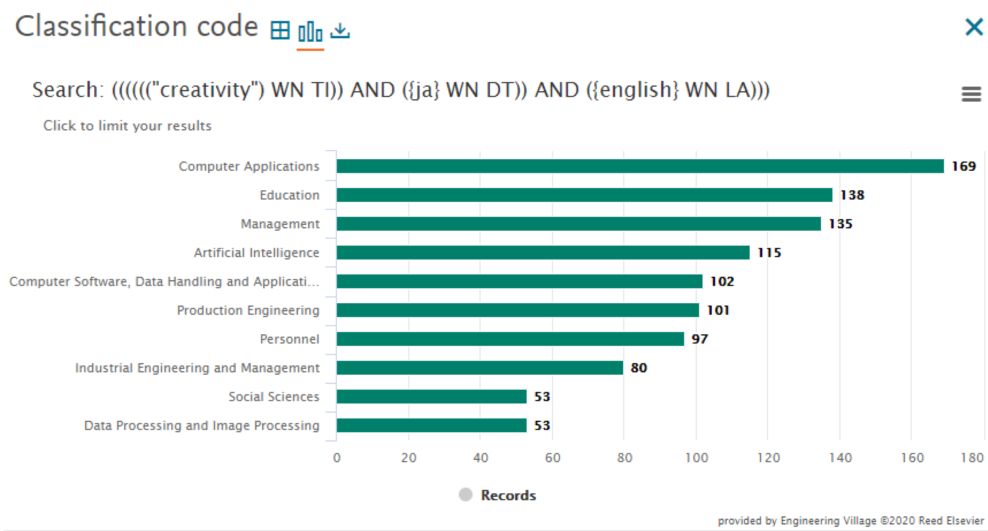

Figure 7: The distribution of the classification codes of the 1,214 articles obtained during the last step while searching for articles in Ei Compendex database.

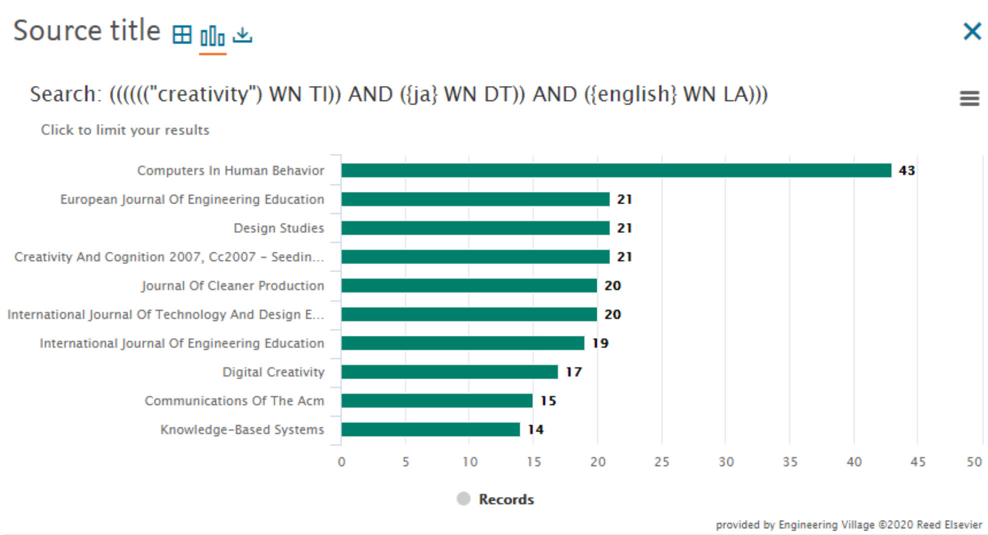

Figure 8: The distribution of the source title of the 1,214 articles obtained during the last step while searching for articles in Ei Compendex database.

Backward Citation Search. After selecting an article based on the selection strategy described in Section 2.5.1.2, reading it thoroughly, and extracting the metadata according to the procedure described in Section 2.5.1.3, a backward citation search is sometimes performed to find relevant articles. Similar to the process applied to the articles found through the Ei Compendex Database search outlined earlier in this section, when an article is found through this manual backward citation search process, the article goes through the article selection strategy (Section 2.5.1.2) as well as the data extraction process (Section 2.5.1.3).

2.5.1.2 Articles Selection Strategy

Adding articles to the corpus through the two strategies outlined in the previous section will continue until enough articles are found.

Ei Compendex Database. For the articles found through the search performed on Ei Compendex Database, the selection process started by sorting the found articles in reverse chronological order, i.e., from newest to oldest, based on publication date. After that, the articles are inspected one by one by reading their titles and abstracts. If an article was determined to be related to creativity, it was downloaded and skimmed to confirm the initial findings. If the article was found to be related to the study of creativity, it was queued for the data extraction step (Section 2.5.1.3).

Backward Citation Search. The articles found through the backward citation search go through the same selection criteria described for the articles found through the Ei Compendex database search strategy mentioned in the previous paragraph. Their relevance to the creativity research is first determined, and if the article was deemed relevant, it was queued for the data extraction step (Section 2.5.1.3). Otherwise, the article was simply ignored.

2.5.1.3 Data Extraction Process

Upon determining that an article is related to creativity, it was read thoroughly, and the explicit definition used for creativity, if any, was extracted and placed in the corpus. If no explicit definition was given, a definition was constructed based on how creativity was measured. The information about whether an explicit or implicit definition for creativity was given in the article was included in the corpus. Besides the explicit/implicit piece of metadata, other information was kept about each article added into the corpus. The complete list of information kept about each article is presented in Table 2. The extracted metadata will answer the research questions posed in this chapter and be used when answering the research questions posed in Chapter 3 and Chapter 4. They will also be used to inform the design of the experiment in Chapter 5.

Table 2: A list of the metadata information kept about each article included in the of creativity definition corpus extracted from engineering articles.

Field	Description
Summary	A short summary (2-3 sentences) of the paper.
Area	The creativity area (person, product, process, press, interaction between multiple areas, and/or external effect) that the paper is focusing on. More information about these areas will be discussed in Chapter 3.
Level	The creativity level (min-c, little-c, ed-c, Pro-C, or Big-C) the paper is focusing on. More information about these levels will be discussed in Chapter 3.
Factors	The list of factors that has been studied by the article for their effect on creativity. The factors are categorized based on the different creativity areas, see the "Area" metadata row for more information. More information about these factors will be discussed in Chapter 4.

2.5.2 Building Generic Creativity Definition Corpus

The generic corpus was built based on a report of creativity definitions compiled by Treffinger (2011). The report was initially published in 1996 and revised in 2011. The 1996 version of the booklet contains 100 creativity definitions, while the 2011 version contains an additional 25 creativity definitions. The definitions in both the 1996 version and the 2011 version were extracted from the generic literature. The 2011 version is the one that was used to build the generic corpus.

The 1996 version of the booklet classifies the included creativity definitions into one or more of the following groups: creative act/actions, creative attitude, creative orientation, creative productivity, creative response, creative thinking, creative work, creativity/creative process, critical thinking, good thinking, higher-order thinking, ingenuity, inventive level, lateral thinking, and thinking operations. The 2002 version, on the other hand, omitted such classification. Both versions of the booklet start with a brief introduction to the creativity definition topic followed by the compendium of the definitions. The complete reference was given at the top of each creativity definition. The creativity definitions were quoted directly from the reference, but some include additional clarification text when appropriate.

In addition to the definitions extracted from the booklet collected by Treffinger (2011), additional definitions were found and selected through frequent casual searches and backward citation searches. The identified articles were selected based on the details presented in Section 2.5.1.2. When the article meets the selection criteria, its associated information was included in the corpus based on the procedure explained in Section 2.5.1.3.

2.5.3 Data Analysis

Before analyzing the built corpora, a pre-processing step is necessary. The pre-processing step is performed by applying the following set of normalizing techniques: (a) putting terms in proper *lowercase form*, (b) *tokenizing*, i.e., breaking each definition into a set of terms, (c) *stemming*, i.e., removing word ending such as ‘ing,’ ‘ed,’ and ‘s’ from the terms to elicit the stems, (d) *lemmatizing*, i.e., replacing words that are close in meaning with one that represents all, e.g., replacing the terms “am,” “are,” and “is” with “be,” and (e-f) *removing standard stopwords*, i.e., terms that do not have any meaning such as ‘the,’ ‘a,’ and ‘and’ and *custom stopwords*, i.e., words of places or people that may appear in the corpora but do add any meaning. Such stopwords are usually encountered while analyzing the corpora. When the corpora are ready for analysis, a set of exploratory data analytics techniques is performed to build a high-level understanding of the corpora. The next step is to apply a set of statistical modeling techniques to uncover any latent topics in the corpora.

Some of the exploratory data analytics techniques that were considered are (a-b) tabulating the *most frequent words* and visualizing them as *wordclouds*, (c) visualizing the *word co-occurrence networks*—a weighted network where the nodes represent words in the corpus and the weights on the edges between any pair of words indicate the number of definitions in which this pair of words appear, and (d) *correlation networks*—similar to the co-occurrence network but take into consideration how often the pair of words appear together in a definition relative to how often they appear separately. On the other hand, some of the statistical modeling techniques that have been considered are *topic modeling* such as Latent Dirichlet Allocation (LDA, Blei, Ng, & Jordan, 2003) and *word-network analysis* such as Louvain Community Detection (LCD, Blondel, Guillaume, Lambiotte, & Lefebvre, 2008). The topic modeling techniques, such as LDA, are data reduction techniques. They are used to capture the variance in many variable (the distinct words, other than the stopwords, in the corpus when dealing with text) in a smaller, easy-to-work-with set of variables (topics which are mix of words when dealing with text). On the other hand, the word-network analysis techniques, such as LCD, are relationship description techniques. They are used to describe the relationship between units of analysis. The nodes in the network represent the units of analysis (the unique words in the corpus when dealing with text) and the links between any two nodes represent the relationship between them (e.g., being in the same definition in case of analyzing a corpus of definitions). The word-network analysis techniques will cluster the words into sets based on the strength of the relationship between the words within the same set which gives a visual cue about the different clusters (e.g., topics in case of text) that may present in a given corpus (Bail, 2016; Rule, Cointet, & Bearman, 2015).

2.6 Results & Discussion

This section reports the results obtained after applying the data analysis process described in Section 2.5.3 on the corpora built via the procedures outlined in Section 2.5.1 and Section 2.5.2 to answer the research questions posed in Section 2.4. The results for each of the posed research question is presented on a separate section below.

2.6.1 RQ1.1: What aspects of creativity are being focused on in the engineering literature?

A total of 42 creativity definitions were collected from the engineering literature based on the process explained in Section 2.5.1. To gain an overall understanding of the corpus, a set of summarization and visualization techniques were used: top frequent words, wordcloud, word co-occurrence network, and word correlation network, as shown in Figure 9, Figure 10, and Figure 11.

(a) Top Frequent Words (b) Wordcloud (freq ≥ 5%)

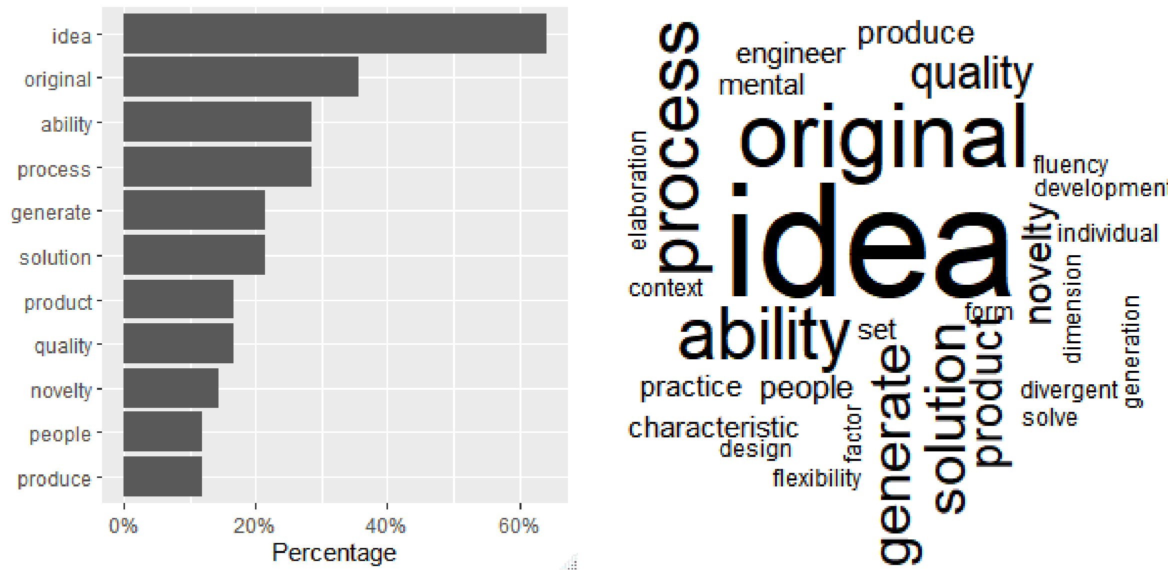

Figure 9: A visual summary of the top frequent words in the engineering corpus.

As shown in Part (a) of Figure 9, more than 60% of the definitions in the engineering corpus used the term ‘idea’ when defining creativity; 20-40% of the definitions used the terms “original,” “ability,” “process,” “generate,” and/or “solution” when defining creativity; and 10-20% of the definitions used the terms “product,” “quality,” “novelty,” “people,” and “produce” when defining creativity.

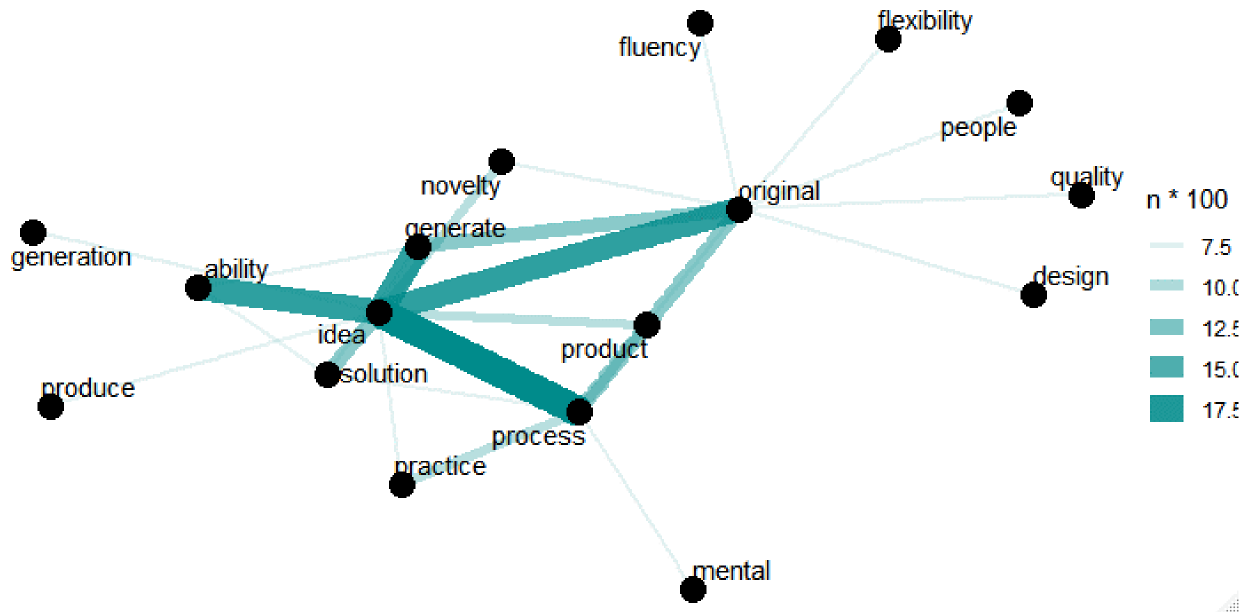

Figure 10: A visual summary of word co-occurrence network (freq ≥ 5%) of the engineering corpus.

When considering the co-occurrence of pairs of terms, Figure 10 shows that the term “idea” co-occurs (in the exact definition) with terms such as “ability,” “generate,” “original,” “process,” and “solution” in more than 12% the definitions included the engineering corpus.

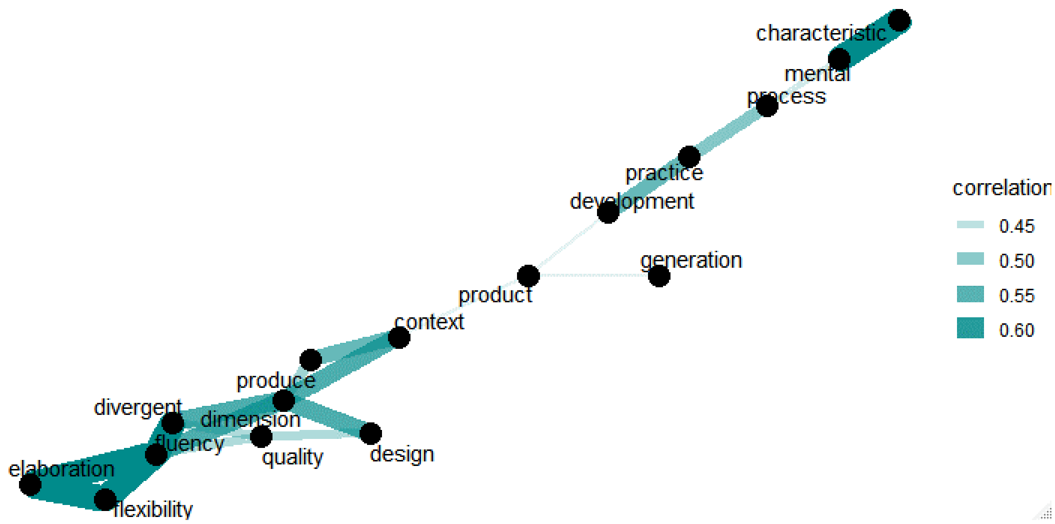

Figure 11: A visual summary of the word correlation network ($r \geq 0.4$) of the engineering corpus.

On the other hand, when considering the association between pairs of terms, Figure 11 indicates that the terms (a) “characteristics” and “mental;” (ii) “elaboration,” “flexibility,” and “fluency;” (iii) “fluency” and “divergent;” (iv) “divergent” and “dimension;” (v) “fluency” and “dimension;” (vi) “dimension” and “design;” and (vii) “dimension” and “context” have a strong association ($r \geq .5$) when considering the definitions in the engineering corpus.

To reveal different latent (hidden) topics that the creativity definitions in the engineering corpus are addressing, the Latent Dirichlet Allocation (LDA) modeling technique (Blei et al., 2003) with an expected 6 latent topics was used. In addition, the

Louvain Community Detection (LCD) network analysis technique (Blondel et al., 2008) was employed. The application of these techniques on the engineering corpus is shown in Figure 12 and Figure 13, respectively.

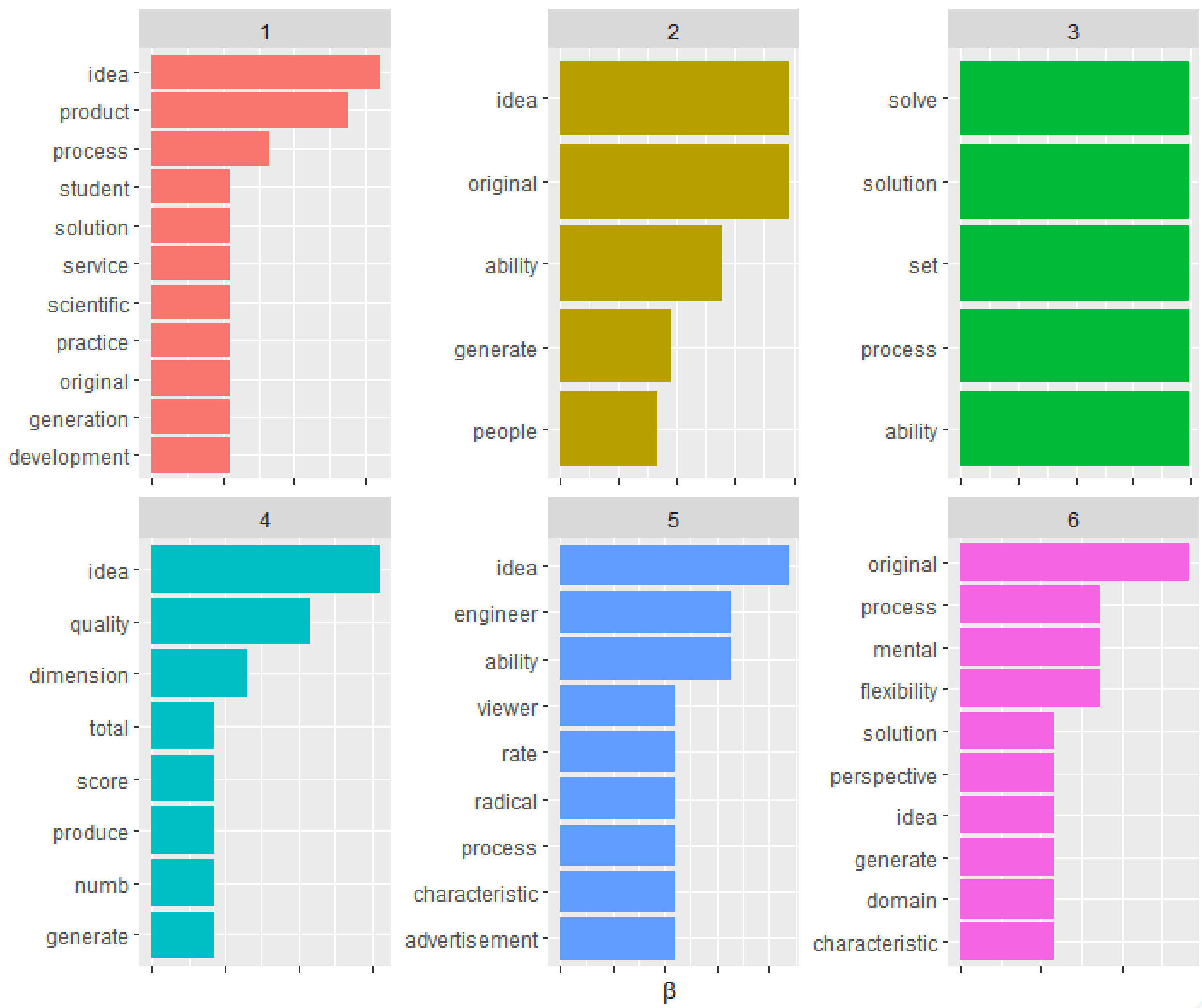

Figure 12: Top terms in each LDA topic in the engineering corpus.

The results of the LDA modeling technique on the engineering corpus presented in Figure 12 show that out of all the terms presenting in the corpus, the term "idea" contributed the most in 3 out of the 6 latent topics, i.e., Topic 1, 4, and 5. The term "idea" also contributed equal top importance with the term "original" in Topic 2 and equal adequate importance with the terms "solution," "perspective," "generate," "domain," and "characteristics" in Topic 6.

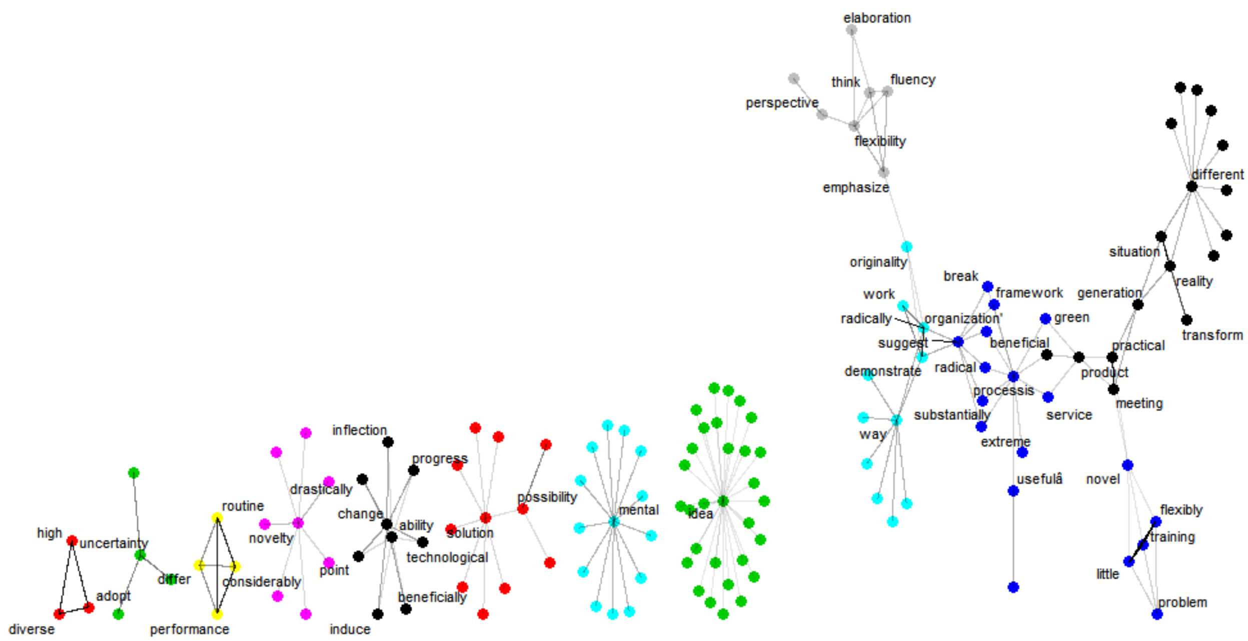

Figure 13: A visual summary of word communities within the engineering corpus.

The results from the application of LCD (Figure 13) suggest the existence of 12 communities of words within the engineering corpus, as shown via the distinct colors used to fill the nodes of each community. Out of these 12 communities, 4 are interconnected, i.e., the ones on the right-hand side in Figure 13, while 6 are disconnected, the ones on the left-hand side in Figure 13. Also, half of the 12 communities consist of 10 or more terms, while the other half consists of only 3-9 terms.

2.6.1.1 Discussion

The results reported in Figure 9 suggest the definitions in the engineering corpus focus on three themes, namely, the *product theme*, the *process theme*, and the *characteristics theme*. The *product theme* emphasizes the importance of producing "something" as a sign of creativity and is signified by the terms: "idea," "solution," "product," and "design." The *process theme* emphasizes that creativity is a process and is signified by the terms: "ability," "process," "generate," "produce," "practice," "mental," "development," "generation," and "divergent." The *characteristics theme* emphasizes that a produced product or a person needs to possess certain qualities to be labeled creative. This theme is signified by the terms: "original," "quality," "novelty," "fluency," "flexibility," and "elaboration."

In addition to the three main apparent themes that the definitions in the engineering corpus are focusing on, one more minor apparent theme also present, namely, the *social theme*. The social theme highlights the role that society plays when determining that the produced product is creative or not. The social theme is signified by the two terms: “people” and “context.”

The latent topics presented in Figure 12 also seem to support the apparent three themes reported in Figure 9, i.e., the product theme, the process theme, and the characteristics theme. Topic 1 seems to focus on the product theme through the two most contributing terms: “idea” and “product.” Topic 2 and Topic 4 seem to focus on the characteristics theme through the most contributing term “original” in Topic 2 and the second contributing term “quality” in Topic 4. Topic 5 seems to focus on the process theme through the second most contributing term, “ability.” Topic 3 and 6, on the other hand, seem to be a mix of two or more themes—Topic 3 is a mix of the product theme and the process theme, while Topic 6 is a mix of the process theme and the characteristics theme.

The communities of terms presented in Figure 13 also seem to highlight the same apparent themes discussed earlier, i.e., the product theme, the process theme, and the characteristics theme. The five connected communities on the far right address the characteristic theme while the one in the middle, the green community with the term ‘idea’ in its middle, addresses the product theme. The community to the left of the middle, the green-colored community, the one colored cyan and has the word “mental” in its middle, focuses on the process theme. The smaller communities to the left of the cyan-colored community that consists of more than five terms seem to focus on, from right to left, the product theme (the red-colored community), the process theme (the black-colored community), and the characteristics theme (the pink-colored community).

2.6.2 RQ1.2: What aspects of creativity are being focused on in the generic literature?

A total of 128 creativity definitions were collected from the generic literature based on the process explained in Section 2.5.2. To gain an overall understanding of the corpus, a set of summarization and visualization techniques were used: top frequent words, wordcloud, word co-occurrence network, and word correlation network, as shown in Figure 14, Figure 15, and Figure 16.

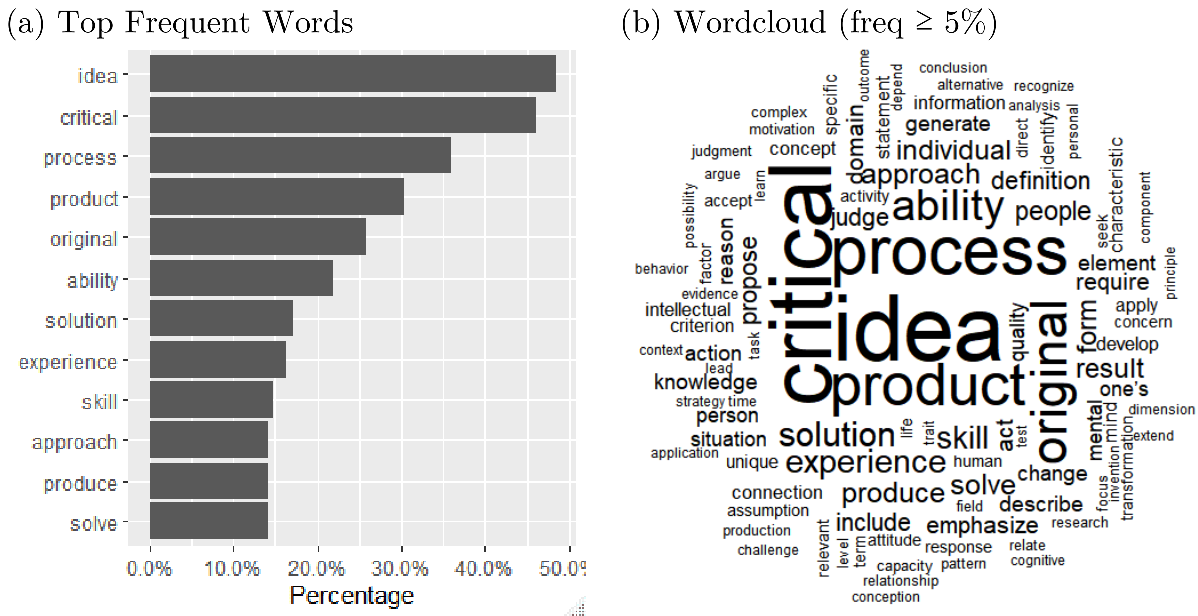

Figure 14: A visual summary of the top frequent words in the generic corpus.

As shown in Part (a) of Figure 14, more than 45% of the definitions in the generic corpus used the terms "idea" and/or "critical" when defining creativity; 20-40% used the terms "process," "product," "original," an/or "ability;" and 10-20% used the terms "solution," "experience," "skill," "approach," "produce," and/or "solve."

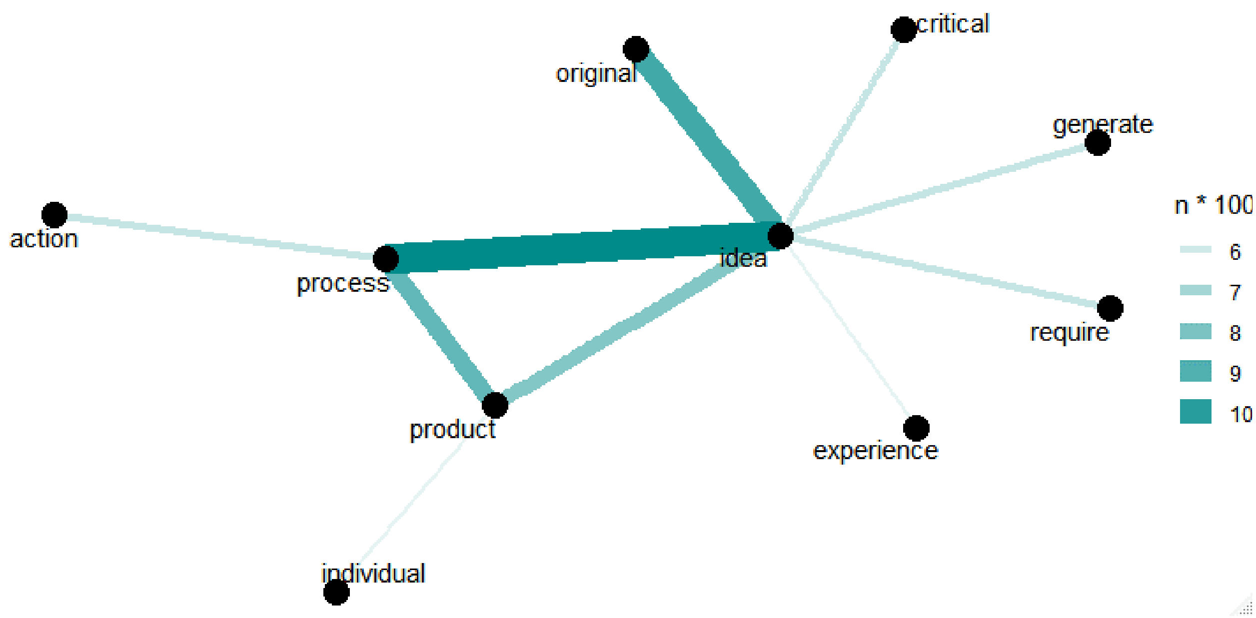

Figure 15: A visual summary of word co-occurrence network (freq ≥ 5%) of the generic corpus.

When considering the co-occurrence of pair of terms within the exact definition in the generic corpus, the results in Figure 15 indicate that the term "idea" co-occurs with the terms "process," "original," and "product" between 8-10% of the definitions. In contrast, it co-occurs with the terms "critical," "generate," and "require" in 7% of the definitions. The term "process," on the other hand, appears with the term "product" in 8% of the definitions and with the term "action" in 7% of the definitions.

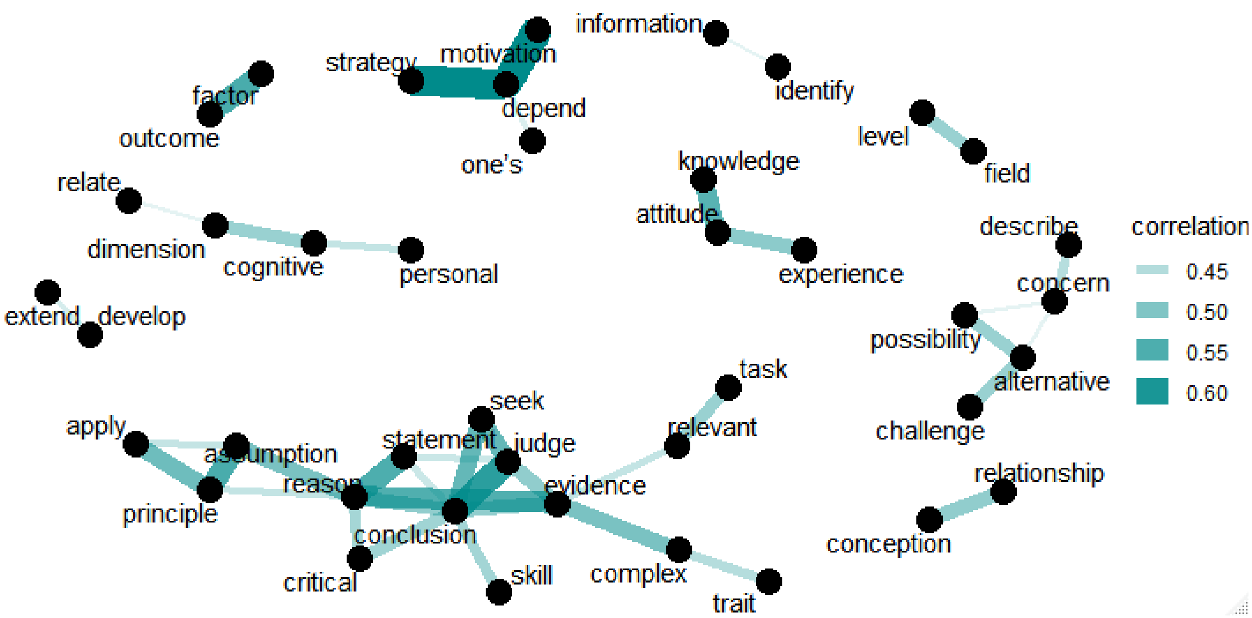

Figure 16: A visual summary of the word correlation network (r ≥ 0.4) of the generic corpus.

When considering the strength of the associations between pairs of terms in the definitions of the generic corpus, Figure 16 shows that there is a strong association (r ≥ .5) between the following terms: (i) "strategy" and "depend;" (ii) "depend" and "motivation;" (iii) "knowledge" and "attitude;" (iv) "attitude" and "experience;" (v) "factor" and "outcome;" (vi) "apply" and "principle;" (vii) "principle" and "assumption;" (ix) "assumption" and "reason;" (x) "reason" and "statement;" (xi) "conclusion" and "judge;" and (xii) "evidence" and "complex."

To understand the different latent (hidden) topics that the creativity definitions in the generic literature are addressing, the same techniques used on the engineering corpus, i.e., LDA modeling technique with 6 expected latent topics and LCD network analysis technique, were used. The results of the application of these approaches on the generic corpus are shown in Figure 17 and Figure 18.

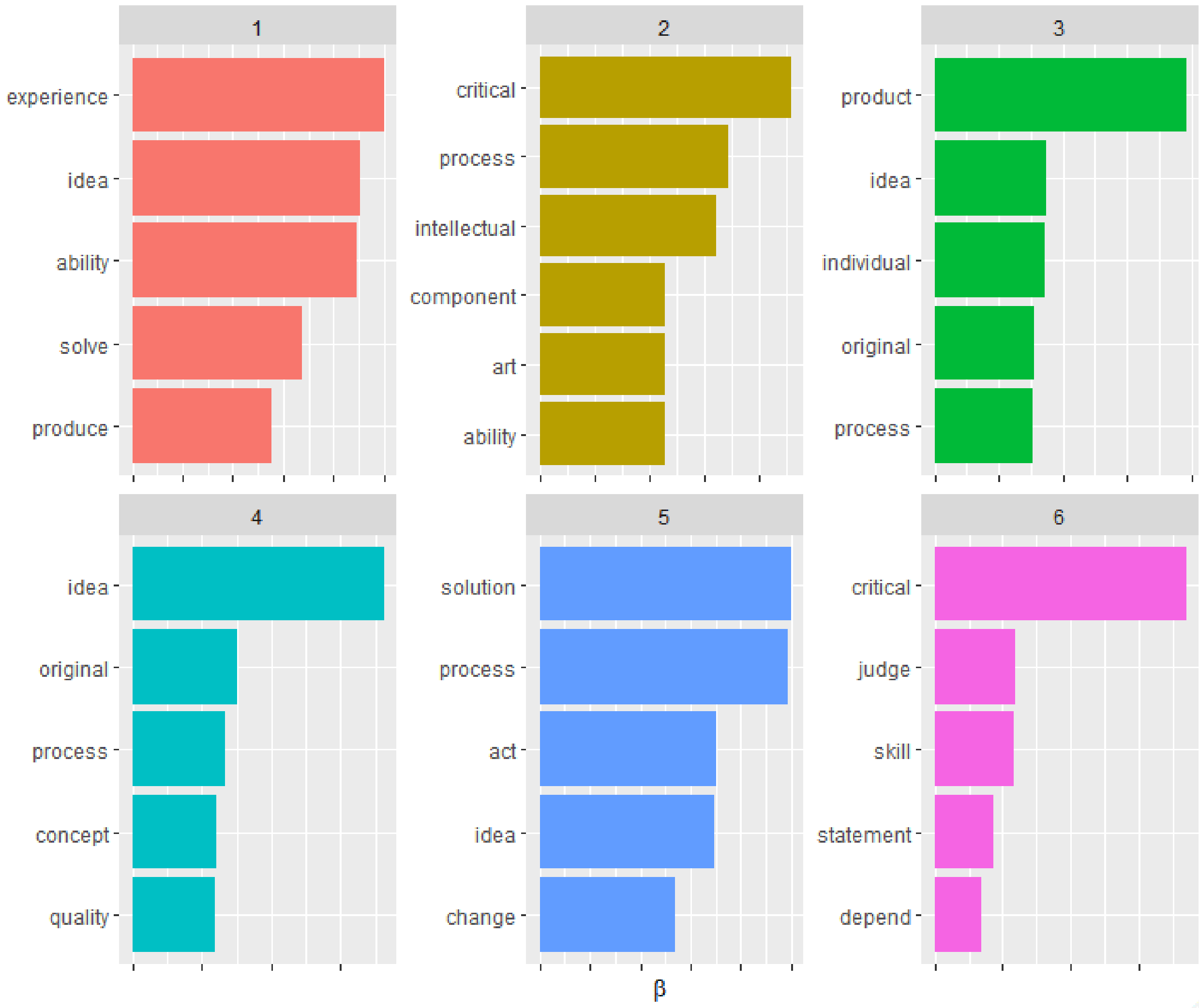

Figure 17: Top terms in each LDA topic in the generic corpus.

The results from the LDA modeling technique presented in Figure 17 show that the term “product” is the most contributing term to Topic 3, the term “idea” is the most contributing term in Topic 4, and the term “critical” is the most contributing term in

Topic 6. The rest of the topics, i.e., Topics 1, 2, and 5, include terms that contribute almost equal importance to the topic. For example, the term “experience,” “idea,” and “ability” contributed almost equal importance in Topic 1, while the terms “solution” and “process” contributed equal importance in Topic 5.

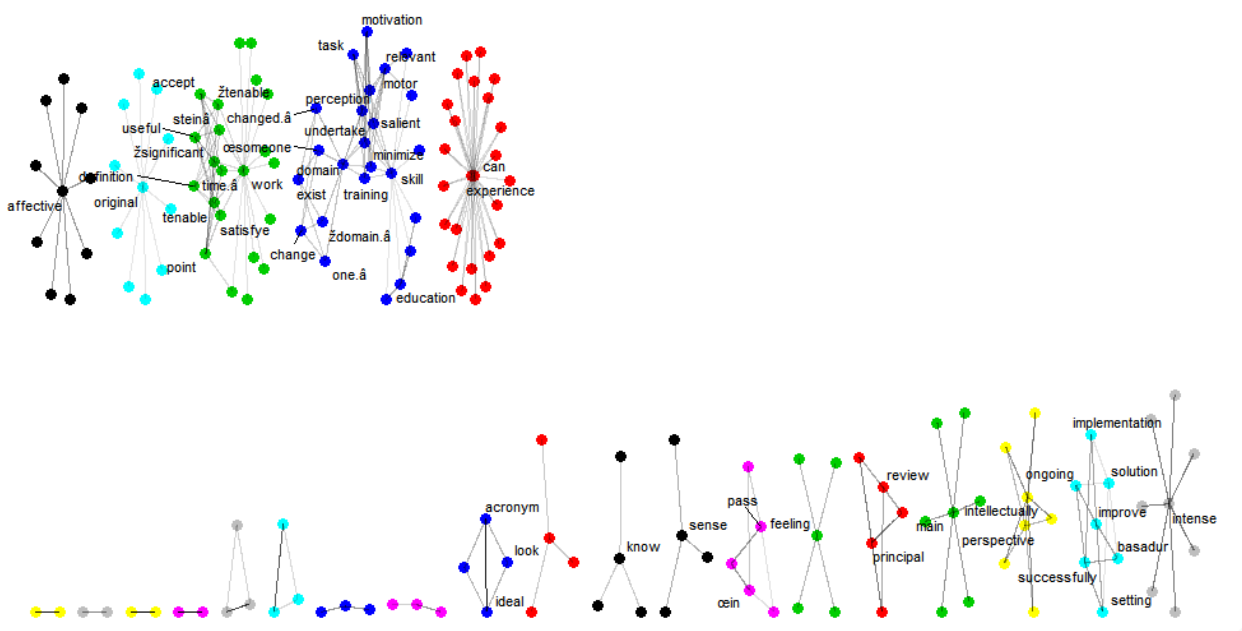

Figure 18: A visual summary of word network for the generic corpus.

When considering the communities of words generated via the LCD network analysis technique, the results in Figure 18 suggest that a total of 24 communities of words, indicated by the distinct colors used to fill the nodes of each network, exist. Out of these communities, only 3 are interconnected (the ones on the top-left corner of

Figure 18), while the remaining 21 communities are disconnected. Out of these 24 communities, only 5 communities consist of 10 or more terms, i.e., the ones on the top section of Figure 18, while the rest consists of 6 or fewer terms, i.e., the ones on the bottom section of Figure 18.

2.6.2.1 Discussion

The results from the analysis of the generic corpus presented in Figure 14 suggests a new theme, the *mental process theme*, in addition to the three themes observed in the results of the analysis of the engineering corpus, i.e., the product theme, the process theme, and the characteristics theme. The mental process theme places emphasis on the process that goes inside the head of the creator and is signified by the terms: “critical,” “attitude,” and “cognitive.” The other themes, i.e., the product theme, the process theme, and the characteristics theme, followed the same focus found in the engineering corpus and are signified by similar terms mentioned in Section 2.6.1.1.

The six latent topics elicited from the generic corpus presented in Figure 17 seem to focus on all the four themes mentioned in the previous paragraph except the characteristic theme. Topics 1 and 4 seem to focus on the process theme—signified by the most contributing terms: “experience,” “ability,” “solve,” and “produce” in Topic 1 and the term “idea” in Topic 4. Topics 2 and 6 seem to focus on the mental process theme—signified by the term “critical” in both topics and the term “intellectual” in Topic 2. Topic 3 seems to focus on the product theme and is signified by the most contributing term, “product.” Topic 5, on the other hand, is a mix of two themes: the product theme signified by the most contributing term “solution” and the process theme signified by the most contributing term “process.”

The large communities of terms presented on the top left-hand side of Figure 18 seem to highlight all the themes presented earlier in this section except the product theme. The far-left community, colored black and where the term “affective” sets in its middle, focuses on the metal process theme. The community to its right, the cyan-colored one, seems to focus on the characteristic theme. The following community, which is the one colored green, has no clear focus. The following two communities, the one colored indigo and the one colored red, seem to focus on the process theme.

2.6.3 RQ1.3: How is engineering different from generic literature when defining creativity?

The results of comparing the most frequent terms used in the engineering corpus to those used in the generic corpus (Figure 19) show that 44% of the top frequently used terms are shared between the two corpora, namely, the terms “solution,” “product,” “produce,” “process,” “original,” “idea,” and “ability” with the term “idea” represents the most frequently used term in both corpora when defining creativity. The “quality,” “people,” “novelty,” and “generate” were typical only in the definitions used in the engineering literature. At the same time, the terms “solve,” “skill,” “experience,” “critical,” and “approaches” were only common in the definitions used in the generic literature. The term “critical” appears very frequently in the generic literature (in more than 40% of the definitions); however, it was completely missing from the most frequently used terms in creativity definitions in the engineering corpus.

Given the practical nature of engineering, it comes with no surprise that the scholars, when defining creativity in engineering, emphasize terms such as “quality” and “novelty,” which represent the heart of the characteristic theme. On the other hand, it is also no surprise that the definitions in the generic corpus focus on terms such as “experience,” “critical,” and “approaches,” which are linked with the process theme and the mental process theme. These themes focus on the steps required to form creative ideas and how these ideas come to existence in the creative person’s head.

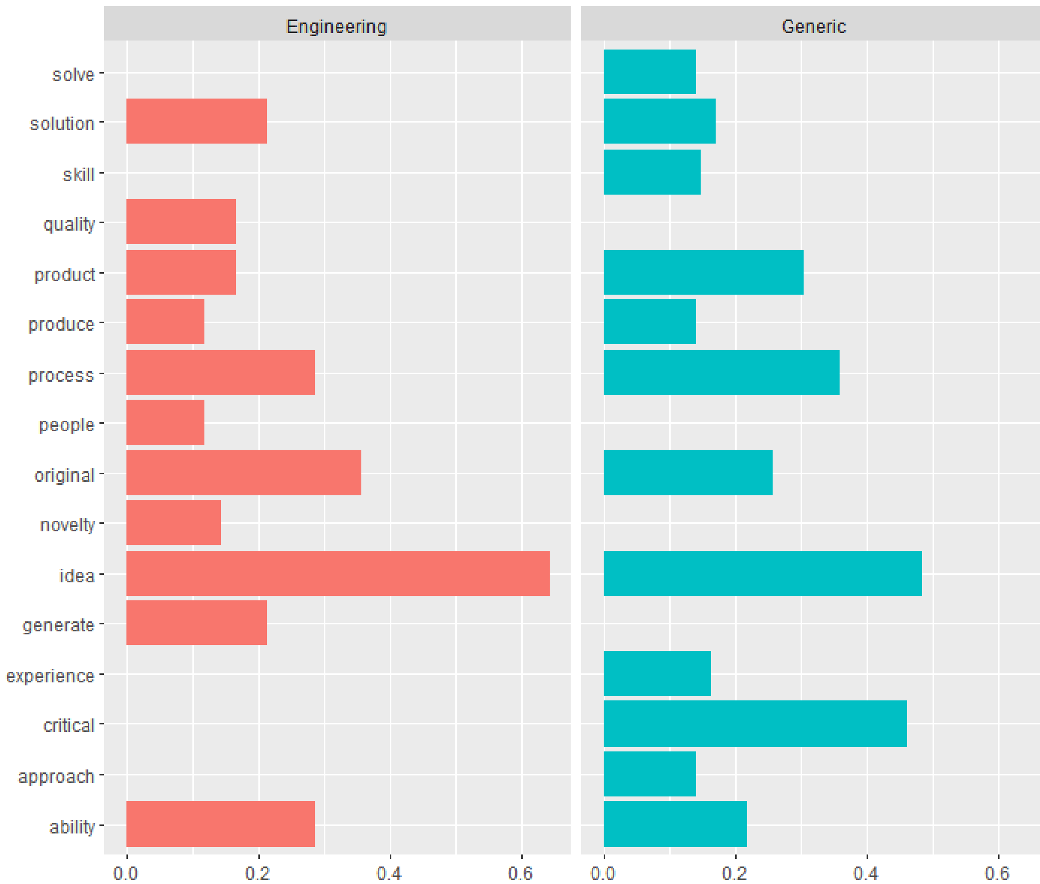

Figure 19: A comparison of the top frequent words in the engineering and generic corpora.

2.6.4 RQ1.4: What aspects of creativity are missing from definitions?

When taking into consideration the analysis performed on the definitions from the engineering and generic literature (this chapter) as well as the results obtained to the research questions posed in Chapter 3: Creativity Models and Chapter 4: Creativity

Factors, a set of aspects seems to be missing or not being emphasized on when defining creativity. As shown in Figure 19, many definitions use the term “idea” when defining creativity. However, the term “idea” does not capture all the forms of production that people can generate[6]. Using the term “idea” when addressing creativity excludes the other forms of human outcomes representing the manifestation of these ideas, such as artworks and product prototypes[7].

Besides the exclusivity problem that stems from using the term “idea” when defining creativity, most definitions are missing the social aspect. The two-way interaction between the creative outcome and society, i.e., the effect of the creative outcome on society and the collective reaction of the society toward the creative outcome, undoubtedly plays a role in defining what is accepted as a creative outcome. Although the social circle may expand or contract based on the level of creativity being addressed, as shown in Chapter 3: Creativity Models, the idea being raised here is that society is not

[6] The essence of term “idea” evolved around the thoughts and images being formulated in the mind (Merriam-Webster, 2021).

[7] One may argue that such forms of human outcomes start with ideas before they get manifest, and this is true. The argument here, thought, is about the usage of the term “idea” when definition creativity and that more inclusive term should be used was what will be suggested in the next research question.

a significant aspect being focused on when defining creativity. The social aspect has been alluded to in the engineering literature by using the "people" term in about 10% of the definitions. Although no similar indications have been found in the most frequent words used to define creativity in the generic literature, the results obtained through topic modeling showed a trait of such aspect in Topic 6, as shown in Figure 17. The trail is indicated through the term "judge," which is usually performed by an outside entity that usually belongs to the society where the creative outcome was produced.

2.6.5 RQ1.5: Considering the answers to RQ1.1 through RQ1.4 and the answers to RQ2 and RQ3, what an appropriate definition of creativity can be proposed?

Based on the answers to the previous four research questions, any adequate definition for creativity should cover five themes: the product theme, the process theme, the characteristic theme, the mental process theme, and the social theme. In addition, the definition should take into consideration that creativity is not a single thing and that it can take different levels that range from creativity recognized by the individual her/himself only to the eminent creativity being recognized by a large group of people as described in details in Chapter 3: Creativity Models. Although it may not be directly related, any definition for creativity needs to consider the varied factors that may affect creativity, as described in detail in Chapter 4: Creativity Factors. Taking all these points into consideration and after several iterations and reflections on the topic, the following definition for creativity shown in the box below has emerged.

> Creativity is a **deliberate process** to produce an **act** that is at <u>minimum</u> **novel** and **useful** to the **circle** in which it was introduce, even after a while.

The definition emphasis (a) the product theme by using the term “act;” (b) the process theme by using the term “process;” (c) the characteristic theme by using the terms “novel” and “useful” and indicating their necessity beside other characteristics using the term “minimum;” (d) the mental process theme by using the term “deliberate” as a quality of the process; and (e) the social theme by using the term “circle.”

2.7 Opportunities and Future Work

A set of technical details regarding the corpus building strategies and the data analysis procedures performed in this chapter used to answer the posed research question in Section 2.4 can be considered in the future. This section highlights these opportunities and discusses the difficulties that may be encountered when implementing them. The section covers the following sets of opportunities: (i) opportunities regarded to the corpora building strategies, which will be covered in Section 2.7.1, (ii) opportunities related to preparing the built corpora for analysis which will be outlined and discussed in Section 2.7.2, (iii) opportunities related to the ways of gaining more understanding of the built corpora which will be covered in Section 2.7.3, and (iv) opportunities related to the ways of coming up with an adequate definition for creativity which will be taken care of in Section 2.7.4.

2.7.1 Corpora Building Strategy

This section covers the opportunities that can be taken into consideration when (a) searching for relevant articles, which will be discussed in Section 2.7.1.1) and (b) selecting articles to include in the built corpora, which will be covered in Section 2.7.1.2.

2.7.1.1 Article Finding Strategy

Searching Engineering Literature. Although the Ei Compendex database represents a comprehensive database for the engineering literature, other engineering databases such as IEEE Xplore and Web of Science can be considered in the future. When considering multiple databases, an additional step to find and eliminate duplicate articles needs to be performed during the selection process described in Section 2.5.1.2.

Forward Citation Search. As opposed to the backward citation search, the forward citation search can be utilized to find relevant papers. The forward citation search can be performed after applying the selection strategy described in Section 2.5.1.2 on the articles found in the databases of choice. Other search strategies such as the *Population/Problem, Intervention/Exposure, Comparison, Outcome model* (Richardson, Wilson, Nishikawa, & Hayward, 1995) or the *wild card search strategy* (Billings, 2003) can also be considered in the future.

Other Booklet of Creativity Definitions. Besides Treffinger (2011)'s booklet of creativity definitions that have been used in this chapter to build the generic corpus of creativity definitions, a search for similar booklets can be considered in the future. One such potential booklet is the booklet collected by Aleinikov, Kackmeister, and Koeing (2000), which includes 101 definitions of creativity obtained from children and adults as oppose to the booklet collected by Treffinger (2011) from the literature.

Using Related Terms. Sometimes, terms such as intelligence, innovation, and genius are used interchangeably or in place of the creativity term. Searching for such terms should be taken into consideration in the future when trying to find articles that deal with/study creativity. When performing such search, however, one needs to be aware of the confusion that exists not only among laypersons but also among researchers when using these terms; for example, although they have slightly different meanings, the terms "innovation" and "creativity[8]" are sometimes used interchangeable (Abraham, 2018; M. Tang, 2017).

2.7.1.2 Article Section Strategy

The strategy used to select articles in this chapter mainly was based on the publication date, i.e., it placed a higher emphasis on recent articles. In the future, more emphasis could be placed on the quality of the conducted research measured through procedures such as the *Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies* (National Heart), *PEDro Scale* (Verhagen, de Vet, de Bie, Kessels, Boers, Bouter, & Knipschild, 1998), *Intervention Efficacy Scale* (van Tulder, Koes, & Bouter, 1997), and/or *Hierarchy of Evidence procedure* (Paci, Cigna, Baccini, & Rinaldi, 2009). The nature of the research conducted by the article will determine the appropriate approach that can be used to measure the quality of the paper.

[8] Although closely related, innovation does not exactly mean creativity; it is creativity in action (Abraham, 2018; M. Tang, 2017).

Besides using the quality of the conducted research as a selection criterion for papers, the level of influence measured, such as the number of citations, can also be considered. Although this criterion seems more straightforward than the quality of conducted research criterion, it suffers from two problems. First, the researchers need to agree on the source from which the number of citations can be extracted. Second, using this criterion gives the older articles a better chance to be selected over the recently published ones since they existed in the literature for a longer time. Hence, their chance of being cited will be higher. A criterion that combines both of these approaches, i.e., the quality of the conducted research and the level of influence, can be utilized. Still, it will require more effort to conduct.

In addition to the above more advanced selection criteria, one may also restrict the selection of articles on whether an explicit definition of creativity is given or not. In the selection strategy used in this chapter, it does not matter if an article gives an explicit definition for creativity or not. The most crucial factor for selecting the article is that it deals somehow with creativity. If no explicit definition for creativity is given, the researcher builds it based on how the article assesses it. Such practice may not capture the exact meaning of creativity the article ought to investigate. It could be that what is in the authors' minds about creativity is different from how they assessed it.

2.7.2 Preparing Corpora for Analysis

Stopword Removal. The standard approach used in this chapter to prepare the corpus for data analysis includes a step where the standard stopwords get removed. However, removing such stopwords may alter the meaning of the results obtained in the subsequent steps. For example, assume that one entry in the corpus defines creativity by differentiating it from intelligence as follows: "creativity is not the same as intelligence." Removing the stopwords "is," "not," "the," and "as" will yield the following phrase "creativity same intelligence," which gives a different meaning. If "same" is also a stopword, then the phrase "creativity intelligence" will be the outcome of the stopword removal process, which is even worse in meaning than the phrase with the "same" word in it. Although this problem may not surface when having many definitions, it is undoubtedly an issue that needs to be considered in the future.

Data Coding. One way of coding text to prepare it for analysis is to use the term-document frequency (TDF) technique used in this chapter. This technique is based on counting the number of times specific terms appear in each document without considering any of the adjacent words, i.e., the context in which it appears. So, if the word "original" appears 10 words after the word "useful" or next to it, this TDF technique cannot capture such a difference. The only piece of information that the TDF technique can provide is that the word “original” appears with the word “useful” in the exact definition; that is all! Hence, other techniques such as word embedding (Mikolov, Sutskever, Chen, Corrado, & Dean, 2013) need to be considered in the future to allow for a more meaningful analysis of the collected creativity definitions.

2.7.3 Understanding Corpora

When forming a general understanding of the obtained creativity definitions, standard techniques, i.e., most frequent words, wordcloud, word co-occurrence networks, and word correlation networks, have been used. Other techniques that consider the semantic meaning of the definitions can also be employed in the future. Taking the semantic meaning into consideration can be achieved either by employing a coding technique that takes into consideration the semantic meaning built into the definitions as described in Section 2.7.2 or by calculating the semantic distance (Li, McLean, Bandar, Shea, & Crockett, 2006) between each pair of definitions following it by an unsupervised clustering (Grira, Crucianu, & Boujemaa, 2004) to group the definitions into distinct categories. The resulting categories can then be analyzed separately to understand the unifying topic they address when defining creativity. The result obtained through this method can be compared to the results obtained through the LDA technique as described in Section 2.5.3.

However, the problem that may arise here lies in finding an adequate algorithm that can be used to calculate the semantic distance between pairs of creativity definitions.

Besides considering the semantic meaning of the collected definitions, one can try to understand the evolution in understanding creativity over time. The evolution approach can be achieved by grouping the collected definitions based on the date on which the definitions were first published then analyzing each group of definitions separately. All the techniques employed in this chapter or those suggested in this section can be considered when studying the evolution of understanding creativity over time. In addition, the techniques employed to elicit the underlying latent topics can also be used to understand the shift in topics that the definitions are focusing on over time. The periods that the researcher can take could be fixed, e.g., 5-year periods, or based on significant events that happened within the creativity literature or outside the creativity literature. One may also take the opposite direction by starting with different lengths of periods. Upon discovering changes in the understanding of creativity, go back and search for evidence of events that contributed to such changes in understanding.

2.7.4 Definition Construction

The work performed here took a data-driven approach. A set of definitions was first collected from the literature and then analyzed to highlight the main components focused on when defining creativity and discovering any latent topics through specific analytical topic modeling techniques. Other approaches that can be considered in the future are (i) the etymology approach[9] that can be used to analyze and explain the root of the "creativity" word, and (ii) the usage-driven approach that can be used to understand how people and/or researchers[10] use the "creativity" concept. These approaches can also be considered when trying to produce a definition for creativity.

The process of producing a good definition for any concept is a fundamentally challenging task. Such difficulty it was recognized, according to Podsakoff et al. (2016), by Mill (1875) a century ago when noting that "to define, is to select from among all the properties of a thing, those which shall be understood to be designated and declared by its name; and the properties must be well known to us before we can be competent to determine which of them are fittest to be chosen for this purpose" (p. 8). Nonetheless, a systematic approach such as the one followed in this chapter, which is in some way similar

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[9] See Dulgheru (2015), Sharma (2020), Jordanous and Keller (2016), M. Tang (2017) and Seelig (2012) for short discussion of the etymology of creativity.

[10] The work done by Aleinikov et al. (2000) where 101 definitions of creativity were collected from adults and children can be a good start.

to the recommendation provided by Podsakoff et al. (2016), can be utilized to construct an adequate definition for creativity.

3
CREATIVITY MODELS

"Models are useful, but only a fool follows them blindly."

—Paul E. Plsek

3.1 Introduction

A basic understanding of the available creativity models is critical in studying creativity. However, when reviewing literature to fill this need, no clear outline of these models exists. When searching the literature with the term 'creativity model,' researchers are overwhelmed by the vast number of available ones. To show the magnitude of the available creativity models, a search has been performed on fourteen databases that the author has access to, namely, Knovel, ASME Digital Collection, AIAA Electronic Library, PsycTESTS, ERIC, PsycARTICLES, JSTOR, IEEE Xplore, GEOBASE, ACM Digital Library, PsycINFO, Web of Science, Compendex, and Google Scholar. The search was performed on December 1st, 2020. The search of the two terms 'creativity model' (without any quotations) was performed three times: one on the title field, one on the title and abstract fields (when available), and one on all the fields. Figure 20 shows the number of papers obtained using the three search criteria on the databases mentioned above.

Although no systematic review has been performed to eliminate irrelevant and duplicate papers or obtain additional papers through backward and forward searches, the reader can see many possible models of creativity. Such a substantial number of models, let alone the myths and misconceptions surrounding the creative phenomena (e.g., see Beaty, Kenett, Christensen, Rosenberg, Benedek, Chen, Fink, Qiu, Kwapil, Kane, and Silvia (2018); Osborn (1953, 1963); Plucker, Beghetto, and Dow (2004); Sternberg and Lubart (1996) for a discussion), usually detours or at least confuses those who would like to study creativity (Sternberg & Lubart, 1996). Hence, a mapping of the landscape of the creativity models is a necessity—more about the importance of such classification will be mentioned in the next section.

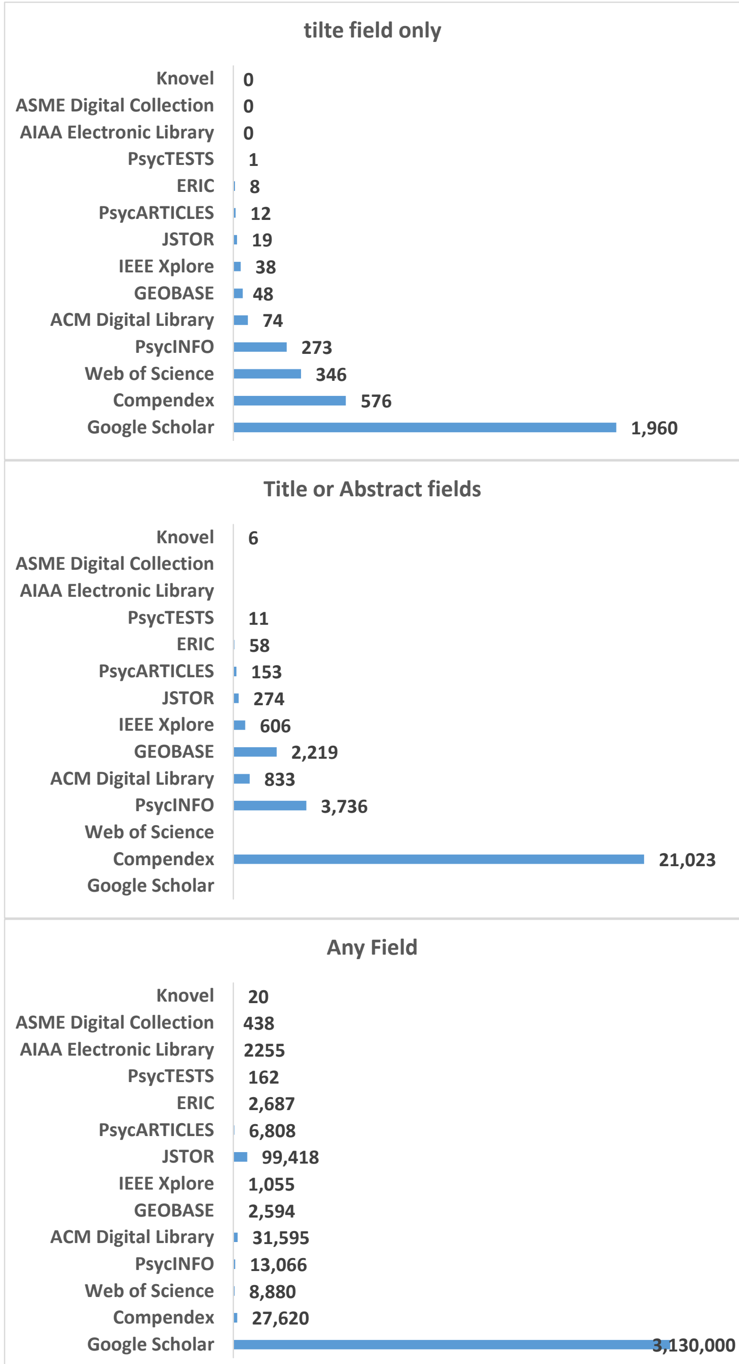

Figure 20: The number of results obtained when searching multiple databases for the term 'creativity model' using different fields, i.e., the title field (top), the title or abstract fields (middle), and any field (bottom). The entries without values in the top-right figure, i.e., In Title or Abstract, indicate that the database does not support searching the abstract field or does not support searching terms in either the title or abstract, i.e., searching using the OR operator is not supported.

3.2 Motivation

The motivation behind this chapter is to assist researchers, interested in studying creativity, with a roadmap of the diverse groups of creativity models that exist in the literature. Such a roadmap will give the researchers the ability to classify any creativity model that they came across into one of the roadmap's proposed categories and elevate some of the mental overloads that result from the vast literature available on the topic. Such a roadmap will also make navigating the literature of creativity models more effective and fruitful and, hopefully, push the creativity research forward, as evident in the history of sciences (Rhodes, 1961)[11]. As Rhodes (1961) puts it: ‘every branch floundered until facts were organized and classified’ (p. 309).

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[11] Rhodes (1961) pointed to the importance of classifications in advancing sciences. He mentioned that *astronomy* took a big step forward after grouping ‘the heavenly bodies, outside of the sun and moon, into plants and fixed stars’ (p. 309); that *physics* took a big step forward after ‘grouping its phenomena into a broad categories of dynamics, sound, heat, light, electricity, and magnetism’ (p. 309); and that *biology* become a science ‘[w]hen [Carl] Linn[ae]us devised the system of binomial nomenclature,’ the modern system of naming organisms (p. 309) where he ‘organized flora into phyla and into classes’ (p. 310).

3.3 Chapter Outline

This chapter is organized as follows. First, the research questions that the chapter will answer are listed in Section 3.4, followed by a description of the methodology, in Section 3.5, which outlines the process used to answer the posed research questions. The answers to the posed research questions will be reported in Section 3.6 and the corresponding discussion whenever appropriate. Section 3.8 will present some of the opportunities that can be pursued to improve the obtained results.

3.4 Research Questions

The main research question that will be answered in this chapter is RQ2: What models of creativity exist? The question will be tackled by answering the following sub-research questions, as also shown in Figure 2:

- RQ2.1: What categories of creativity models exist?
- RQ2.2: What models fit under each category?

3.5 Methodology

The approach taken to answer the posed sub-research questions in Section 3.4 consists of two steps. First, an overall understanding of the existing models for creativity will be sought via searches using the generic search engines accompanied with searches on the academic databases. While performing this search, an electronic diary note will be maintained, and any emerging themes of models will be noted. By the end of step 1, the answer to RQ2.1: What categories of creativity models exist? will be obtained.

After finishing the first step of the process, the second step will be to start by conducting a more focused academic search. The forward and backward citation search strategies will be utilized to obtain more models. By the end of this step, the answer to RQ2.2: What models fit under each category? shall be reached.

3.6 Results & Discussion of Each Category of Models

Upon performing the first step of the methodology outlined in Section 3.5, the results indicate that creativity models can be divided into the following main categories:

- those that classify creativity into different types and levels, Level Models, which will be further discussed in Section 3.6.1);
- those that organize the landscape of creativity research into different themes, Thematic Models, which will be covered in Section 3.6.2;
- those that ought to understand the creative process, Process Models, which will be described in Section 3.6.3;

- those that dive into the metal process involved in creativity, Mental Models, which will be taken care of in Section 3.6.4; and
- those that study the factors that ecologically affect creativity, Ecological Models, will be expanded upon in Section 3.6.5.

The creativity framework within which this section works is that a creative act must be at least (a) *novel*, unprecedented in the society in which the act was introduced and is not copied from somewhere else by the creator, and (b) *useful*, to some degree, to the society in which it was introduced judged by the society itself immediately or after a while (Batey, 2012; Craft, 2001; D. H. Cropley & Kaufman, 2012; Lee, Therriault, & Linderholm, 2012; Mayer, 2014; Mumford, 2003; Runco & Jaeger, 2012; Said-Metwaly, Van den Noortgate, & Kyndt, 2017a; Zeng, Proctor, & Salvendy, 2009). Regardless of the widespread agreement that novelty and usefulness represent the bare minimum requirements for an act to be labeled creative, the exact definition for novelty and usefulness is debatable[12] (Batey, 2012; Batey & Furnham, 2006; Runco & Jaeger, 2012). In each of the following sections that will discuss the different categories of creativity

[12] The debate around the definition of creativity was referred to in Chapter 2.

models, i.e., Level Models, Thematic Models, Process Models, Mental Models, and Ecological Models sections, the models that fall into that category will be reported without any discussion or with only a minimal one. The discussion of the reported models will be placed into a separate sub-section toward the end of each section of that category. This way, the reader will clearly distinguish between what was reported in the literature about the models and my view. It is also worth mentioning that the illustrations provided for the models are not borrowed from the literature unless the source from where it was borrowed is mentioned in the illustration caption or somewhere in the corresponding text.

3.6.1 Level Models

Classification models focus on distinguishing between different levels of creativity that are usually tied to the level of knowledge and experience[13,14] (Jackson & Lassig, 2020; Kraft, 2005). This section is divided into subsections where the creativity classification models are introduced evolutionarily, i.e., a chronological order. In the last subsection, I will supply a discussion around the reported models.

[13] Although important, knowledge and experience of the domain of the problem in which a creative act is sought do not guarantee reaching such creative acts. Conversely, such deep knowledge and experience may have a negative effect on creativity (Corazza & Agnoli, 2018; Kraft, 2005; Webb, Little, & Cropper, 2018) unless this deep knowledge and experiences is accompanied by openness (Corazza & Agnoli, 2018) which explains why experienced people could struggle when solving 'insight' problems related to their field of expertise (Webb et al., 2018). Guglielmo Marconi, for example, who was not expert in the field of electromagnetic theory and application invented the radio in 1895 at an age of 21-year old (Corazza & Agnoli, 2018). As Mumford, Martin, Elliott, and McIntosh (2018) put it, "expertise provides only a necessary condition for creativity … [w]hat is as critical, if not more critical, is how people work with this expertise to generate creative problem solutions" (p. 148). Since this section is devoted for reporting on the different creativity models that discriminate between the different levels of creativity, the discussion of the factors that impede or enhance creativity will be deferred when discussing the Ecological Models (Section 3.6.5).

[14] Some researchers questioned the validity of the Level Models, for a discussion please see Runco (2018).

3.6.1.1 2C Model = little-c + Big-C

Little-c creativity is the type of creativity that happens every day.

2C model distinguishes between two types of creativity: *everyday creativity*, known as *little-c creativity*, *Little-C Creativity (LCC)* or *ubiquitous creativity*; and *eminent creativity*, known as *Big-C creativity*, *High Creativity*, *Big-C Creativity (BCC)*, or *Scientific Creativity* (Banaji, Burn, & Buckingham, 2006; Craft, 2001; Craft, Jeffrey, & Leibling, 2001; Simonton, 2003). Visually, we can imagine little-c creativity stands on one end of the creativity continuum while Big-C stands on the other. *Little-c creativity* represents everyday solutions that are unusual such as combing up with a new dish by combining ingredients that usually do not put together or finding a use for scrap materials laying around in the garden. These little-c creative acts are normally recognized by the performer and people in their everyday circle but not by society as a whole (Jackson & Lassig, 2020). This type of creativity is 'not based on a domain[15] of knowledge' (Banaji et al., 2006, p. 28).

Big-C creativity significantly shifts the domain in which it was introduced or create a whole new domain.

Big-C creativity is linked with highly recognized accomplishments and contributions that alter, redefine, or reform a domain by bringing new understandings or perspectives; or create new domains, direct or indirect (Craft, 2001; Csikszentmihalyi, 2013, 2014b; Simonton & Lebudaiza, 2019). In other words, the Big-C creativity significantly shifts the domain in which it was introduced, or it creates a whole new domain. Therefore, it is sometimes linked with *ingeniousness*, mainly when the creator produces many high-quality masterpieces that affect the world around us (Simonton, 1991, 1995; Simonton & Lebudaiza, 2019). Examples of such Big-C creators who altered a domain are Picasso, who "altered painting," Einstein, who "altered physics," and Martin Luther King, Jr.,

[15] Csikszentmihalyi (1990, 1999)'s definition of the domain will be adopted in this chapter. Csikszentmihalyi (1990, 1999) argued that 'each scientific or technological specialty contains two essential components': the *domain* and the *field* (Simonton, 2003, p. 478). The *domain* is a large but finite set of facts, concepts, techniques, heuristics, themes, questions, goals, and criteria. The *field* on the other hand consists of all those individuals who are working with the domain.

who "altered the practice of protest politics in the United States" (Gardner, 2013, p. 3). The Big-C creative acts push the domain forward and are recognized by society immediately or after a while (Csikszentmihalyi, 2013; Gardner, 2013; Jackson & Lassig, 2020).

Little-c and Big-C creativities received most of the creativity research focus compared to the other levels of creativity that will be introduced in the following sections (Kaufman & Beghetto, 2009). For example, Richards (1990) in her article *Everyday creativity, eminent creativity, and health* and Dittmer (1995) in his book *Local People: The Struggle for Civil Rights in Mississippi* focused on little-c creativity while Simonton (1994) in his book *Greatness: Who Makes History and Why* and Branch (1989) in his book *Parting the Waters: America in the King Years 1954-63* focused on Big-C creativity. An illustrative depiction of the 2C model is shown in Figure 21. The figure illustrates the importance of domain knowledge and experience in Big-C creativity.

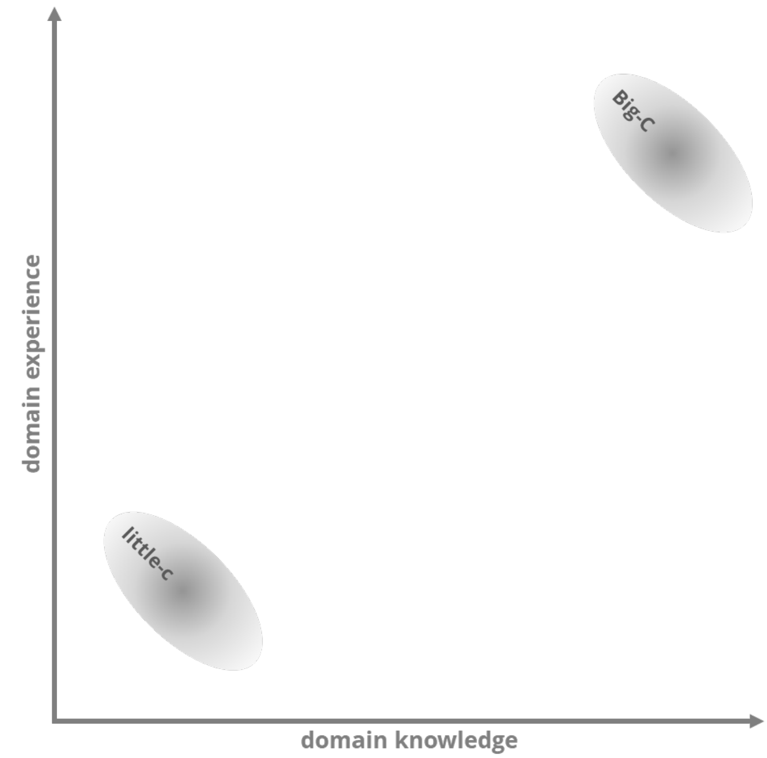

Figure 21: A visual representation of the 2C model of creativity. Domain knowledge and experience play a key role in Big-C creativity, while it is not the case for little-c creativity.

3.6.1.2 3C Model = 2C + mini-c

When using the 2C model, any creative act that is not eminent enough will receive the little-c creativity label. The dichotomy of the 2C model means that a creative act of a seven-year-old student will receive the same little-c creativity label of a more creative produced in the same area via an accomplished amateur. The inability of the 2C model to distinguish between those as mentioned earlier two creative acts leads Beghetto and Kaufman (2007) to propose the 3C model where they added the *mini-c creativity* to distinguish developing creativity from the everyday, amateur creativity, i.e., little-c creativity.

Mini-c creativity is about learning; it is when the person has new understating of things; it is intrapersonal.

Mini-c creativity is not meant only to capture the creative acts by kids; it is meant to capture the "initial creative interpretations" through which creators develop and change their understandings of a problem at hand or the world around them (Beghetto & Kaufman, 2007, p. 4). Mini-c creativity is referred to as "intrapersonal" creativity because it is recognized at the individual level and is inherited in the learning process and to differentiate "interpersonal" creativities, i.e., little-c, Big-C, and other types of creativity that will be introduced in the coming sections, that are recognized by outside observers (Beghetto & Kaufman, 2007; Jackson & Lassig, 2020; Lassig, 2012). Mini-c creativity can be seen as the initial stage of the other types of creativity, i.e., the little-c, Big-C, and the other types of creativity introduced in the following sections. This is because mini-c creativity represents the period when the creator's preceptive of the world changes creatively by having a new, different preceptive or doing things differently. An illustrative depiction of the 3C model

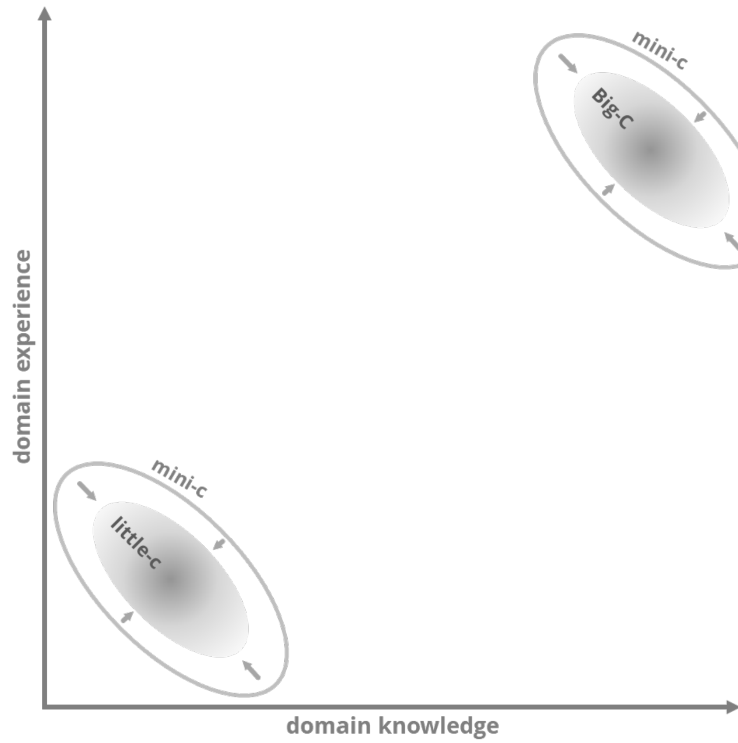

Figure 22: A visual representation of the 3C model of creativity. The mini-c creativity, which represents the change in one's understanding of their domain in particular or the world in general, contributes or precedes the other two types of creativity.

is shown in Figure 22. Notice how the mini-c creativity is preceding the other two types of creativity.

3.6.1.3 4C Model = 3C + Pro-c

Pro-C creativity creates a shift in the field or domain in which the act was introduced; but it is less significant compared to shift introduced by a Big-C creative act.

Two years after proposing the 3C model, Kaufman and Beghetto (2009) extended it and proposed the 4C model. The goal of the 4C model is to distinguish between the amateur creative act and the professional creative act that is not yet eminent. Such a professional creative act is called *Pro-c creativity*. The Pro-c creative act is usually recognized by the professional community in which the act happened. Such an act typically pushes the profession forward but not the whole domain in which the profession resides. An example of the Pro-c creativity act in the literature domain is the Harry Potter series written by J. K. Rowling. Such work is above the little-c creative act of hobbits who write for those in their everyday circle; however, it does not reach the Big-C creative act of those who push the boundaries of the literature domain, such as Shakespeare (Lassig, 2012). Pro-c creative acts are usually forgotten over time except for a few that might be in the future recognized as Big-C creative acts (Kaufman & Beghetto, 2009; Lassig, 2012).

The Pro-c creative act not only emerges from a professional domain, but it can emerge from any domain that a person puts a great deal of effort in where he/she becomes

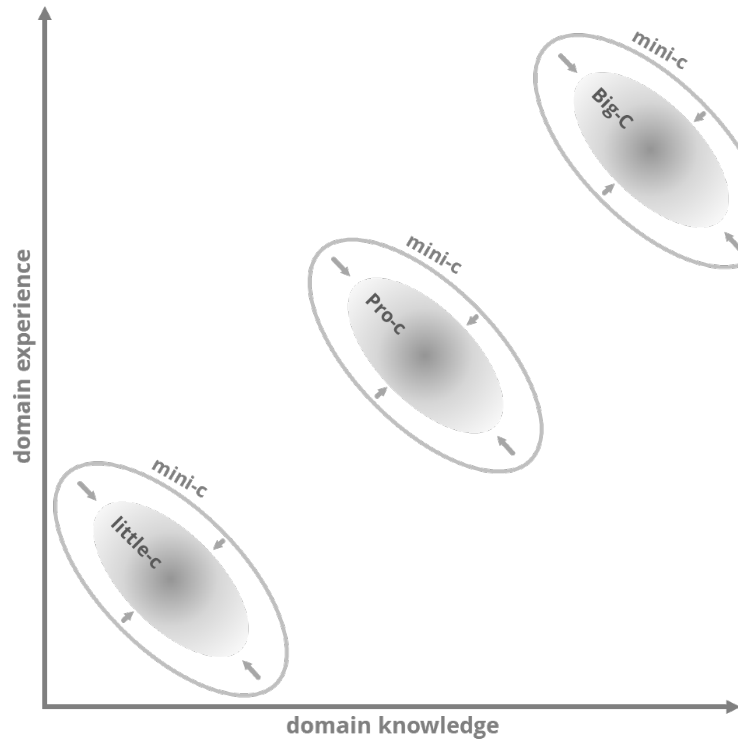

Figure 23: A visual representation of the 4C model of creativity. Pro-c creativity is a stage between the little-c creativity and Big-C creativity; it is a creativity above the little-c but below the Big-C; it is the creativity practices that appears during one's professional work.

an expert in that field as seen by their peers (Jackson & Lassig, 2020). Hence, the Pro-c creativity captures the creative acts by those well-established in their domains, i.e., have a wealth of knowledge and experience. An illustrative depiction of the 4C model is shown in Figure 23.

3.6.1.4 5C Model = 4C + ed-c

Lassig (2012) proposed an extension to the 4C model to capture the creative acts by adolescents in the educational domain. This extension leads to the 5C model, where a new category called *ed-c creativity*, educational creativity, was added. The ed-c creativity sits between the little-c creative and the Pro-c creativity; it captures the creative acts of adolescents while they are in the educational system and transiting to the Pro-c creativity (Lassig, 2012). Creative acts within the student's educational system are considered ed-c creativity; however, if these creative acts went beyond the student's educational system to push a domain forward, they will be classified as Pro-c or Big-C creativity based on the introduced impact.

Lassig (2012) differentiated between three manifestations of the ed-c creativity: *personal expression*, *boundary-pushing*, and *task achievement*. An adolescent's creativity can appear in one or more of these manifestations. Regarding *personal expression*, adolescents can show creativity when expressing themselves—their personalities, emotions, ideas, and values—in numerous ways, e.g., via art, fashion, and way of writing. The *boundary-pushing* manifestation in the ed-c creativity is meant to be within the educational system boundary—curricular and extracurricular. If the boundary-pushing creative act passes this boundary, it will be considered for the other higher levels of creativity, i.e., Pro-c and Big-C creativities. The creativity in *task achievement* manifestation occurs regarding a task created by the adolescent or assigned by an outside entity, e.g., a teacher. The task created by an individual is referred to in the literature by “problem finding” (Jacob W Getzels & Csikszentmihalyi, 1976; Runco & Chand, 1995) or “problem construction” (Mumford, Reiter-Palmon, & Redmond, 1994). An illustrative depiction of the 5C model is shown in Figure 24. In contrast, Table 3 summarizes the 5 creativity levels and how this model, i.e., the 5C Model and the ones mentioned above, i.e., 2C, 3C, and 4C Models, are related to these levels. Table 3 also states whether a certain creativity level is intrapersonal or interpersonal and how widespread the level is in term of the amount of research done on it.

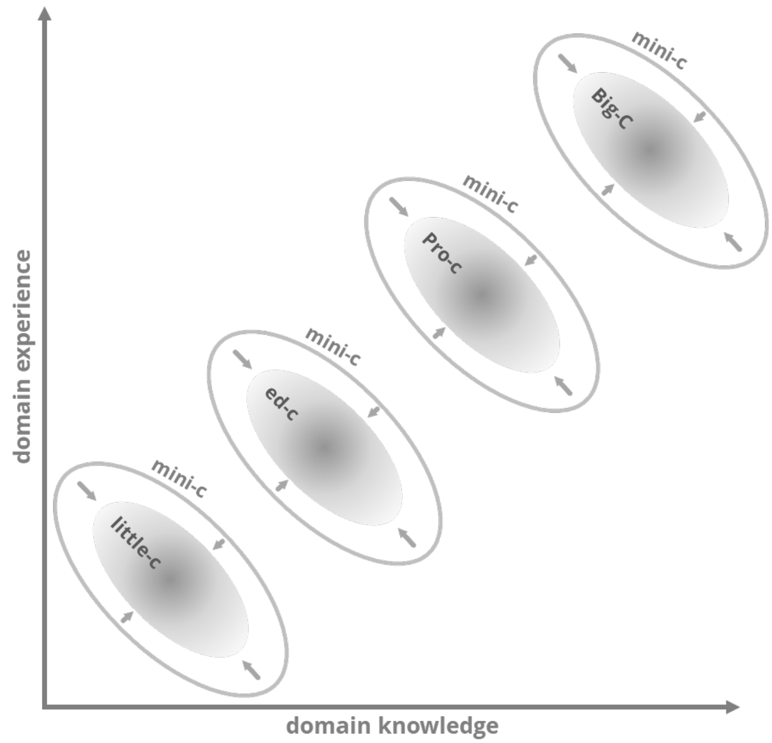

Figure 24: A visual representation of the 5C model of creativity. The ed-c creativity sets between the Pro-c creativity, which occurs during one's professional work, and the little-c creativity, which occurs every day; it is the creativity shown by students during their education.

Table 3: Summary of the five creativity levels encountered in the literature—who proposed each and when, whether the level is intrapersonal or interpersonal, the popularity of each level in literature, and which level appears in each of the four famous models of creativity levels.

creative level ▶	**mini-c**	**little-c**	**edu-c**	**Pro-c**	**Big-C**
first proposed by	Beghetto and Kaufman (2007)		Lassig (2012)	Kaufman and Beghetto (2009)	
intrapersonal	•				
interpersonal		•	•	•	•
popularity in lit	low	high	low	low	high
2C model		•			•
3C model	•	•			•
4C model	•	•		•	•
5C model	•	•	•	•	•

3.6.1.5 Discussion

Big-C Types. Big-C creativity can take different forms. Gardner (1997) distinguished between four groups of Big-C creators[16]: *Masters*, *Makers*, *Introspectors*, and *Influencers*, based on what they focus on. *Masters*, as the name indicates, master "one or more domains of accomplishment" and later come up with creative acts in these domains (Gardner, 1997, p. 11). Rembrandt Harmenszoon van Rijn is an example of the masters of portraiture in the 17th century in Germany (Gardner, 1997).

On the other hand, *makers* may master one or more existing domains, but they focus more on creating a new one. Sigmund Freud is an example of the makers who created the domain of psychoanalysis (Gardner, 1997). *Introspectors* differ from masters and creators in that they focus on understanding themselves in particular and human beings in general. Virginia Woolf is an Introspectors who focused on understanding "her

[16] Howard Gardner, although produced wealth of writings (Gardner, 2020), is well known for his creation of Multiple Intelligences theory. The theory was created to raise the awareness that people have very different types of intellectual strengths. People use their intellectual strengths to learn, to represent ideas in their mind, and to express their understandings to others. Hence, it is unfair to teach all the people the same way and it is illogical to teach in all the different ways. The solution, Gardner argues, is to leverage technology that can deliver personalized contents based on the individual's intellectual strengths (Gardner, 2011).

psyche, the experiences of women, and the nature of the conscious mental process" (Gardner, 1997, p. 2). *Influencers*, as the name suggests, focus on influencing others, directly or indirectly. Mahatma Gandhi is an example of direct influencers through his leadership of different "political and social movement" (Gardner, 1997, p. 12). He is also an example of indirect influencers through his "evocative autobiographical and exhortatory writings" (Gardner, 1997, p. 12).

Big-C types can also be framed using the *Propulsion Model of Kinds of Creative Contributions* proposed by Sternberg, Kaufman, and Pretz (2002). Among the eight proposed types of creativity contributions: *replication*, *redefinition*, *forward incrementalism*, *advanced forward incrementalism*, *redirection*, *reconstruction/redirection*, *reinitiating*, and *integration*, the last five types represent the form of the Big-C creativity. These last five types, i.e., *advanced forward incrementalism*, *redirection*, *reconstruction/redirection*, *reinitiating*, and *integration*, propose a change in the domain that pushes it in an *unexpected* direction, forward or backward, where others are usually not ready. The other three types, i.e., *replication*, *redefinition*, and *forward incrementalism*, do not reach the Big-C level of creativity due to the absence of the 'exception' factor, i.e., the produced act is not exceptional. However, they may fall into the other levels of creativity, as discussed in the corresponding section.

Pro-c vs. Big-C. Pro-c creativity can be thought of as the larger group from which the Big-C creativity stem. In other words, Big-C creativity is a subset of the Pro-c creativity where the creator performs an exceptional act. Using the *Propulsion Model of Kinds of Creative Contributions* framework (Sternberg et al., 2002), one can argue that *redefinition* and *forward incrementalism* types of creativity contribution proposed by the model are forms of Pro-c creativity. Such creativity results in a less exceptional act but has a high degree of useful novelty.

ed-c vs. little-c. Ed-c creativity can be thought of as a particular form of the little-c creativity where the creators are adolescents, and their close circles are not only their families but extend to include their peers and teachers at school. The ed-c creativity is a transitional state between the little-c creativity and the Pro-c creativity where the knowledge and the experience of the person increase and become more specialized. When referencing the *Propulsion Model of Kinds of Creative Contributions* framework (Sternberg et al., 2002), we can apply the *replication* type of creativity contribution on the ed-c level of creativity. This is because creators in their initial stages tend to replicate the work of leading creators in their field with a slight modification.

The 5 Cs in Relation. The five creativity types introduced in this section can be thought of as a subset of one another, as shown in Part (A) of Figure 25. The outer most oval represents the most generic type of creativity, the mini-c creativity, where a change in the understanding of the world happens in the mind of the person, the creator, in a broad term. Mini-c creativity is fundamental to all the other types of creativity, i.e., a state that precedes all the other types of creativity. Mini-c in some of its forms, besides the deliberate form, could be sudden—what is known as insight in the scientific milieu and collegially known as the Aha! or Eureka! moment (Beda, Smith, & Orr, 2020; Kounios & Beeman, 2009; Sprugnoli, Rossi, Emmendorfer, Rossi, Liew, Tatti, di Lorenzo, Pascual-Leone, & Santarnecchi, 2017; Sternberg & Davidson, 1995). Insight moments do not necessarily result in factual information, as Lauldconen, Kaveladze, Tangen, and Schooler (2020) pointed out.

When leaving the mini-c creativity and moving toward the inner most oval, the size of the oval resembles the windspeed of the corresponding creativity category in population. Taking the size of the oval into consideration means that little-c creativity is more widespread in population than ed-c creativity; ed-c creativity is more widespread in population than Pro-c creativity. Lastly, Pro-c creativity is more widespread in the population than Big-C creativity. On the other hand, as shown in Part (B) of the exact figure, i.e., Figure 25, the size of the population who observe the creative act goes in the opposite direction, i.e., the creativity type that is widely spread gets recognized by a

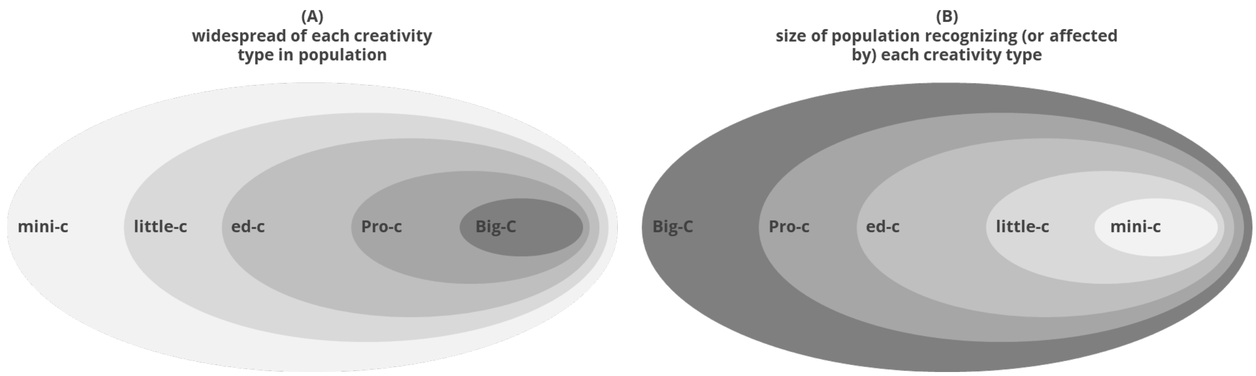

Figure 25: Nested view of the five types of creativity. In part (A) of the figure, the size of the oval represents the widespread of that type of creativity in the population while part (B) of the figure represents the size of the population recognizing or getting affected by that type of creativity. The size of the ovals in part (B) stands for the impact expected by the corresponding level of creativity.

limited number of people. For example, little-c creativity is the most widely spread type of creativity. Still, the number of people noticing the creative act by the little-c creator is only the creator's close circle, their family, and close friends. However, the most narrowly spread creativity, the Big-C creativity, is noticed by many people.

Part (B) of Figure 25 can be used as a classification tool for the creative acts, i.e., acts with widespread impact can be labeled "Big-C," those with less widespread effect can be labeled "Pro-c," and so on. Similarly, Rhodes (1961) suggested classifying creative acts based on the mental processes exerted when generating them, usually tied to the number of generated derivatives. Hence, ideas in *theory* are more creative than ideas for *invention*, which are more creative than ideas for *innovation* (Rhodes, 1961). This is because, from theories such as the relativity theory and the electromagnetic waves theory, many inventions can be germinated (Rhodes, 1961). Similarly, inventions can be re-designed and re-structured in many different ways to create multiple innovations (Rhodes, 1961).

3.6.2 Thematic Models

Thematic models are concerned with organizing the creativity literature landscape into distinct areas based on how researchers view or define creativity and focus when studying creativity. The classification reported in these models does not necessarily mean that the areas are mutually exclusive, i.e., the areas are unrelated. The purpose, as mentioned at the beginning, is to organize and classify the creativity literature. Such classification is necessary for the advancement of creativity research as it is apparent in the history of sciences[17] and, as Rhodes (1961) puts it: "every branch floundered until facts were organized and classified" (p. 309).

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[17] Refer to footnote 11 on page 62 for more information.

It may seem that starting with any of the creativity research areas can lead to the others. Eventually, researchers will converge on the same underlying phenomenon; the reality is different (Simonton, 1988). If a researcher cannot assume that all these areas are cohesively hanging together, they will orientate to one area and subordinate the other areas to this orientation (Simonton, 1988). Hence, understanding the different areas of creativity research is essential in distinguishing between the different creative works found in the literature. Such classification will give the reader the ability to classify any piece of work to the corresponding research area based on the focus exerted by the researchers in that work.

3.6.2.1 3PM Model

In the review paper *Psychological Study of Creativity*, Golann (1963) differentiated between four areas in the creativity research landscape: *products*, *process*, *personality*, and *measurement*, which are visually depicted in Figure 26. Although these areas can interleave, the factor used to classify any work into one of these areas depends on the researcher's view of which areas deserve to be focused on initially. Creativity researchers focusing on *products* believe that creativity is best 'studied through products' (Golann, 1963, p. 548). In other words, products need to be studied first when researching creativity. When a product is judged "creative" in one way or the other, the person and the process through which the person generates the product will also be labeled "creative" (Golann, 1963).

The second group of researchers focuses on the *process* where they view creativity as a temporal sequence of steps through which creative ideas or insights appear (Golann, 1963). Hence, those researchers propose models that they believe, when followed, will lead their users to generate creative ideas.

The third group of researchers focuses on *personality* because they view creativity as "a style of life, the personality in action" (Golann, 1963, p. 559). In their work, those researchers try to answer two questions: (a) what personality characteristics, e.g., contentedness, gentleness, and gloominess, creative people have; and (b) what motivate the creative behavior, e.g., autonomy, self-actualization, and/or unacceptable impulses (Golann, 1963).

The last group of researchers focuses on *measurements* because they view creativity as an outcome of a complex set of traits such as fluency, flexibility, and originality. Hence, they develop or adopt measurements and tests to measure creative abilities and use factor analysis to demonstrate the presence of these trails (Golann, 1963).

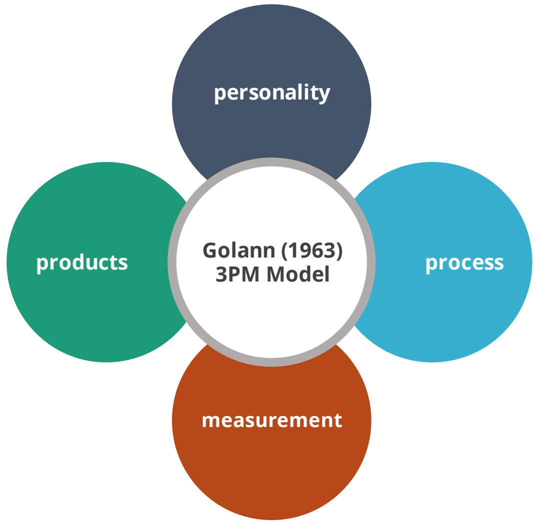

Figure 26: A visual depiction of the four creativity research areas proposed by the 3PM model discussed in Golann (1963).

3.6.2.2 Rhodes 4P Model

After the analysis of 40 creativity definitions and 60 imagination definitions, Rhodes (1961) observed that these definitions overlap but form four unique areas. Although they are unique, these areas need to work in unity to operate functionally (Rhodes, 1961). Rhodes named the four primary areas as *person*, *process*, *press*, and *products*, which are visually depicted in Figure 27.

The *person* area 'covers information about personality, intellect, temperament, physique, traits, habits, attitudes, self-concept, value systems, defense mechanisms, and behavior' (Rhodes, 1961, p. 307). Examples of the questions that can be answered within this area are: What is the relationship between creativity and intelligence? What roles the value systems play on creativity? What are the effects of habits and attitudes on creativity? What enables people to deliver creative work (Simonton, 2003)? Why are some people more likely to deliver creative work than others (Simonton, 2003)?

The *process* area concerns the mental processes that operate when creative ideas are generated (Rhodes, 1961). The area covers 'motivation, perception, learning, thinking, and communicating (Rhodes, 1961, p. 308). In this area, questions such as: Why some people tend to produce creative ideas while others take the conventional route? and, What are the steps to produce with creative ideas? are essentials.

The *press* area 'pertains to the influence of the ecological press on the person and upon his mental processes' (Rhodes, 1961, p. 307). In other words, the press area focuses on studying the relationship between individuals and their environments. What kind of forces plays roles on creative people? How those creative people responses to these forces? are examples of the essential questions in this area.

The *products* area concerns the ideas and thoughts that 'are usually expressed in form of either language or craft' referred to as products and artifacts (Rhodes, 1961, p. 307). In this area, the focus is placed on deciding the creativity level of the produced products. Products can be thought of as artifacts of the creator's thoughts at some point in time (Rhodes, 1961). Hence, the creative products can be used to trace back the thought process, the events, and the circumstances that lead to the ideas of these products (Rhodes, 1961). Researchers who fall in the products area believe that the '[o]bjective investigation into the nature of the creative process can proceed in only one direction, i.e., from product to person and thence to process and to press' (Rhodes, 1961, p. 309). The reason behind focusing on products could be the same as what Sternberg et al. (2002) mentioned when explaining their *Propulsion Model of Kinds of Creative Contributions* that creative people usually have multiple creative products with different creativity levels. Hence, focusing on the creations rather than the creators is more logical.

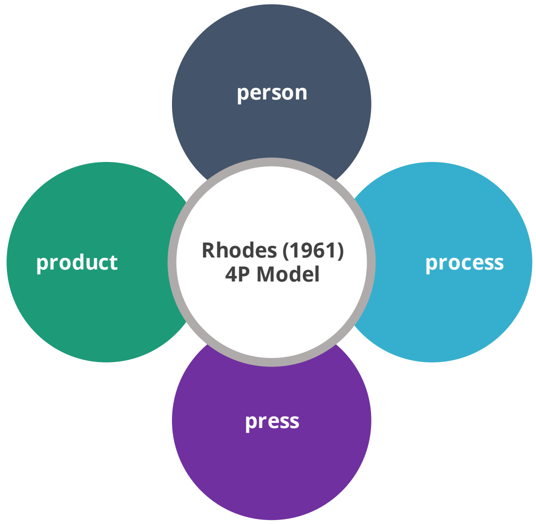

Figure 27: A visual depiction of the four creativity research areas proposed by Rhodes (1961)'s 4P model.

3.6.2.3 Simonton 4P Model

Similar to Rhodes (1961)'s 4P model, Simonton (1988) proposed a 4P model that includes 4 creativity research areas, i.e., *process*, *product*, *person*, and *persuasion*, visually depicted in Figure 29. These areas were proposed based on the researchers' focus when defining creativity, e.g., when defining creativity, some researchers choose to focus on the process while others emphasize the produced product.

The *process* research area is concerned with studying 'the patterns of thought or information processing habits that underlie creativity' (Simonton, 1988, p. 386).

Simonton (1988) pointed out that the creative process is of the same importance to *cognitive psychologists* as the "problem-solving" process, while it is at the same level of importance to the *gestalt psychologists* as the "insight" process[18].

The *product* research area is concerned with studying the outcomes that result from the creative process. It focuses on defining the characteristics, in abstract and practical ways, that need to exist in an outcome to be deemed creative. Having practical definitions for these characteristics is more complicated than it seems, Simonton (1988) argued[19].

[18] There are two groups of thoughts when it comes to the creative process. The first group sees it as a logical process and equate it to the problem-solving process. Hence, this group prefer to study creativity in the lab using problem solving tasks. Conversely, the second group of thoughts sees the creative process more than what the first group of thoughts think, i.e., more than a logical process. Hence, the second group of thoughts tend to use correlational studies to understand the creative process. Refer to Simonton (2003) for an extended discussion.

[19] Simonton (1988) pointed out that for an outcome to be creative, it must simultaneously be "original" and "adaptive." However, practical definitions for these dimensions are in general difficult 'except the realm of artistic' outcomes Simonton (1988, p. 386).

The *person* area is the most prolific, oldest[20], and focused on area of creativity research—scientists, especially the *personality psychologists*, in this area study what individual cognitive and/or motivational differences 'distinguish creative people from those less so' (Barron & Harrington, 1981; Simonton, 1988, p. 386), i.e., what cognitive and/or motivational characteristics make an individual unique from others; what is referred to in psychology as *individual differences* (Feist, 1998).

The *persuasion* research area is concerned with the interpersonal or social phenomena that individuals exert to convince or impress others in their circle with the creative act that they produced (Simonton, 1988). Like the leader who needs to 'have followers to be counted a leader,' a creator must have 'appreciators or admirers' to be considered a creator, Simonton (1988, p. 387) argued. This area of creativity research is what *sociologists* and *anthropologists* focus on (Simonton, 1988).

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[20] The creativity research in the person area started with the work of Galton (1875) with a focus on distinguished scientist where the Fellow of the Royal Society of London were survived. The creativity research in the person's area gain momentum in 1950s where studies on the creative scientists started to appear first followed by studies on the creative individuals (Feist, 1998; Mansfield & Busse, 1981; Martindale, 1989; Simonton, 1988, 2003, 2008). Such research resulted in 'a cornucopia of personality measures' that claim to 'identify creative individuals' (Simonton, 1988, p. 386).

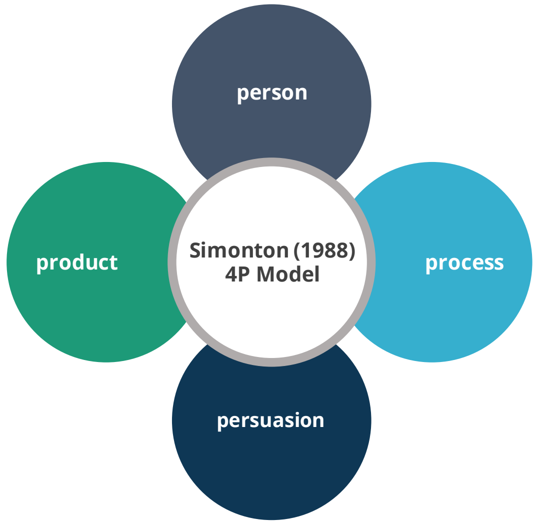

Figure 28: A visual depiction of the four creativity research areas proposed by Simonton (1988)'s 4P model.

3.6.2.4 5P Model = Rhodes 4P + Persuasion

In their paper titled *The 4P's Creativity Model and its Application in Different Fields*, Gruszka and Tang (2017) mentioned that Simonton (1995) extended the 4P model proposed by Rhodes (1961) by adding the *persuasion* area (see Figure 29 for a visual depiction). Gruszka and Tang (2017) mentioned that the rationale behind the extension was that creative ideas usually conflict with the status quo and involve running through many obstacles. Those creative individuals need to think of ways to *persuade* the people in their circles to try or at least accept these creative ideas. Since persuasion is a salient

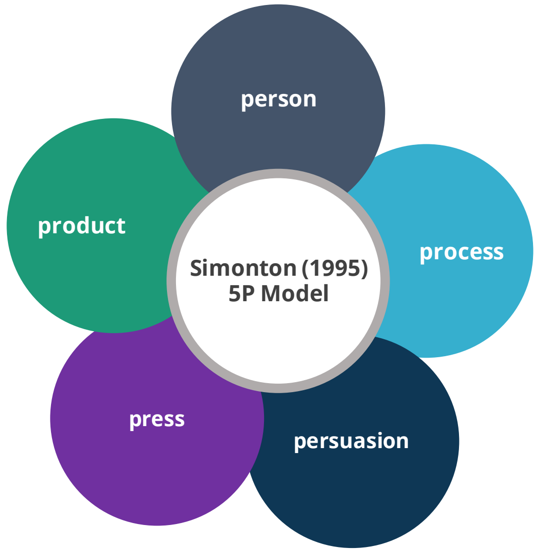

Figure 29: A visual depiction of the five areas of creativity research proposed by Simonton (1995)[1] in Gruszka and Tang (2017).

feature of leaders, Gruszka and Tang (2017) argued that 'creativity might be seen as a form of leadership' (p. 54). The reader is argued to refer to Section 3.6.2.6 for an extended discussion of the confusion that Gruszka and Tang (2017) fell into by attributing the 5P model to Simonton (1995).

3.6.2.5 6P Model = 5P + Potential

Holo:Code (2014) mentioned that R. J. Sternberg extended the 5P model of creativity by adding the *potential* area (see Figure 30 for a visual depiction). *Potential* is defined as

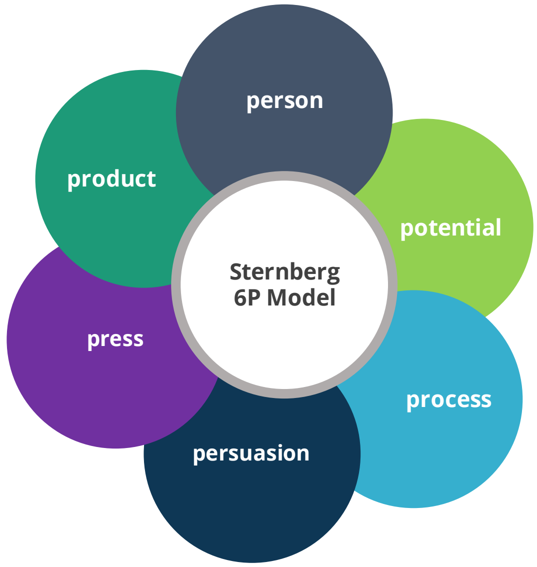

Figure 30: A visual depiction of the six areas of creativity research proposed by the 6P model attributed to R. J. Sternberg in Holo:Code (2014).

the ability to grow and expand ideas and outcomes. Holo:Code (2014) argued that potential is one of the most salient areas in creativity research. The reader is argued to refer to Section 3.6.2.6 for an extended discussion of the confusion that (Holo:Code, 2014) fell into by attributing the 6P models to R. J. Sternberg.

3.6.2.6 Discussion

3PM Model vs. Rhodes 4P Model. Both the 3PM and 4P models fully agreed on two primary areas in the creativity research: product(s) and process. Although they seem to agree on a third area, i.e., personality/person, the person area represents a broader area that includes personality. This makes the person area more inclusive than the personality area. The personality area can be considered a sub-area under the person area, given ample research surrounding it[21].

On another point, the 3PM model suggested measurement as a fourth area while the 4P suggested press. Upon close inspection of the suggested measurement area by the 3PM model, it seems that measurement cannot stand by itself—at the end, we are measuring something, and we need to know this thing to measure it. Hence, the 4P model seems to be more accurate than the 3PM model in suggesting the addition of the press to the primary areas of creativity research. The measurement area proposed by the 3PM model can be considered as a sub-area under each of the areas proposed by the 4P model. This is because the measurement of the impact of each area on creativity is, most probably, not a simple task and requires extensive work.

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[21] In case personality is not a vast area in the creativity research, it can be included as an item under the 'person' research area.

Persuasion in Simonton 4P and 5P Models. The persuasion area introduced in the Simonton 4P model and the 5P model proposed by Simonton (1995)[22] in Gruszka and Tang (2017)[23] does not seem to capture a distinct central area of the landscape of the creativity research. Persuasion can be thought of as a characteristic of the creative individual and hence can be placed as an item under the person area or as a sub-area if the persuasion research related to creativity is extensive enough.

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[22] Although Gruszka and Tang (2017) reported that Simonton (1995) is the one who proposed the 5P model, no evidence in the cited reference was found. Upon searching the literature for more information to confirm who proposed the 5P model or added the 'persuasion' area, no papers were found. However, searching the generic Internet leads to a handout and a webpage where persuasion is mentioned. The handout by Houtz (2001) mentioned no reference while the webpage maintained by Holo:Code (2014) attributed the 5P model to R. J. Stemberg which is most probably not true. R. J. Stemberg is the editor of the book titled *The Nature of Creativity: Contemporary Psychological Perspectives* where Simonton (1988) published a book section titled *Creativity, Leadership, and Chance*. In this book section, Simonton (1988) claimed that creativity is a form of leadership. This gives clue that Gruszka and Tang (2017) most probably meant to cite Simonton (1988) instead of Simonton (1995) in their paper given that Simonton (1995) only discussed the importance of persuasion while in Simonton (1988) he introduced persuasion as another area. This inference was confirmed by Simonton via an email sent to him in January 5th, 2021.

[23] Upon reading Simonton (1995)'s commentary article titled *Exceptional Personal Influence: An Integrative Paradigm* cited in Gruszka and Tang (2017) in their book chapter titled *The 4P's Creativity Model and its Application in Different Fields*, I was not able to find pieces of evidence for the proposed persuasion area. This could be due to referencing error.

Similar to Gruszka and Tang (2017), Simonton (1984, 1985, 1987, 1988, 2009, 2018b) argued that creativity is a form of leadership. As a social psychologist, Simonton (1988) stood for this idea due to the extended years dedicated to studying the 'exceptional personal influence' (p. 386). Gruszka and Tang (2017), on the other hand, most probably, get influenced by Simonton (1988)'s view and took the same stand.

Although creativity is a critical leadership quality to ensure that creative ideas are being generated—by the leaders themselves or by their employees by facilitating and inculpating generated ideas—and accepted by others, creative people are not necessarily leaders. For this reason, the 5P model is not adding any more information to the Rhodes 4P model. That persuasion can be considered a characteristic of leaders who might or might not be creative (see Figure 31 for an updated visual depiction of the Rhodes 4P model after addition 'persuasion' as a sub-research area). This raised the question that if the creator produces a creative work but failed to persuade others of their creation, will the creative work be considered uncreative? Since we are discussing the Thematic Models in this section, the reader is referred to Chapter 4 for a discussion of the distinctive characteristics of creative individuals.

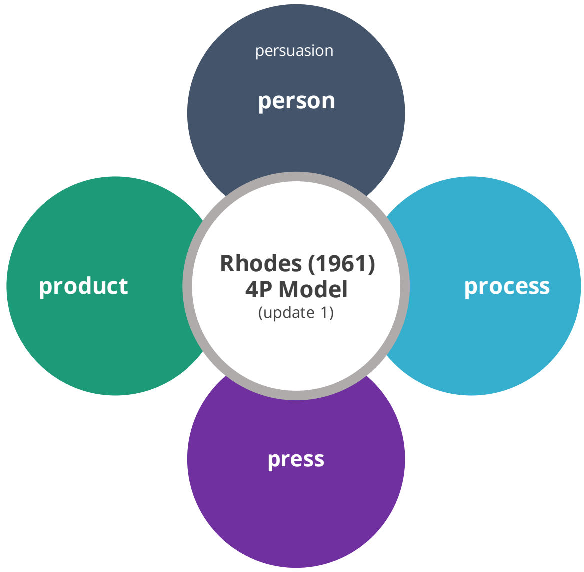

Figure 31: A visual depiction of an updated version of Rhodes 4P model of creativity after incorporating 'persuasion' as a sub research area under 'person.'

6P Model. Like the introduction of the persuasion area to the 4P model to come up with the 5P model was not very distinct, the introduction of the potential area to the 5P model to produce the 6P model (Holo:Code, 2014)[24] was not very distinct as well—the potential area cannot stand by itself. The potential area can be thought of as a

[24] Although Holo:Code (2014) attributed the addition of the potential area to R. J. Stemberg, it is most probably that Simonton (1988) is the one who did so. For a complete discussion of the confusion in citing this reference, the reader is argued to refer to footnote 22 on page 102.

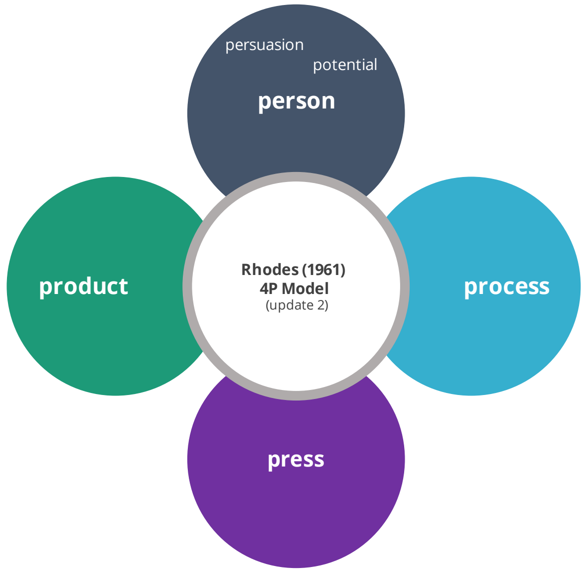

Figure 32: A visual depiction of the 2^{nd} update of Rhodes 4P model of creativity presented in Figure 31 after incorporating 'potential' as a sub research area under 'person.'

characteristic related to the person area. Hence, like persuasion, potential can be included as an item within the person area or as a sub-area if the creativity research related to potential is extensive enough (see Figure 32 for a visual depiction of an updated version of Rhodes 4P model shown in Figure 31 after adding 'potential' as a sub research area).

3.6.2.7 4Pe: 4P-elaborated Model

Based on the discussion reported in Section 3.6.2.6, I propose an elaborated version of the 4P model where a measurement sub-area is included under each of the areas proposed by the 4P model (see Figure 33 for a visual depiction of the proposed model). The reason behind the inclusion of measurement as a sub-area under each of the other 4 areas is that measurement is a focal (Kaufman, Baer, Cole, & Sexton, 2008; Park, Chun, & Lee, 2016; Plucker & Makel, 2010; Said-Metwaly, Van den Noortgate, & Kyndt, 2017b) and broad topic (Barbot, Besançon, & Lubart, 2016; Batey, 2012; Fishkin & Johnson, 1998; Plucker & Makel, 2010; Rhodes, 1961) within creativity research and hence deserves its sub-area. It is also worth mentioning that despite the considerable progress made in the research area of creativity measurement, many challenges are still unresolved (A. J. Cropley, 2000; Lemons, 2011; Park et al., 2016; Plucker & Runco, 1998; Said-Metwaly et al., 2017b; Zeng, Proctor, & Salvendy, 2011) which give another reason for why the measurement was included as a sub-area by itself.

One may include personality as a sub-area under the person area due to the expected large amount of creativity research. However, since the study of the person covers personal trails (personality) besides others (Karwowski & Lebuda, 2015), I decided not to include personality in the elaborated model as a sub-area by itself. Similarly, one might include persuasion (proposed in Simonton 4P model and the 5P model) and potential (proposed in the 6P model) as part of the person area; however, I decided not to do so for the following reasons. Although persuasion and potential represent smaller

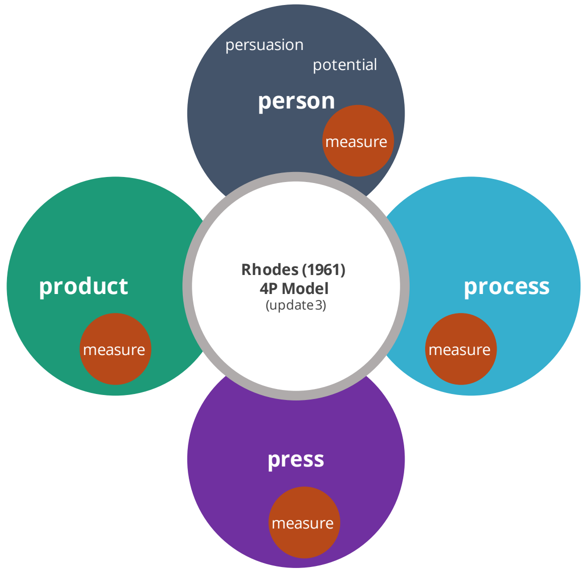

Figure 33: A visual depiction of the proposed 4Pe model which represents an elaborated version of Rhodes 4P model.

research areas than personality, the reason for not including them under the person area as sub-areas by themselves is the same for not including personality—they are already included in the person research area.

3.6.3 Process Models

Process models focus on naming the different steps involved when generating creative solutions. They are different from the *creativity techniques*, *tools*, and *methods* such as *Brainstorming* (Osborn, 1953, 1963), *Synectic* (Wilson, Greer, & Johnson, 1973), *Morphological Chart* (Cross, 2021), *TRIZ* (Altshuller, 2000), and *Six Thinking Hats* (de

Bono, 1956). The creative process models ought to guide their users on how and when to apply these various creativity techniques, tools, and methods, if needed, to produce creative acts (D. H. Cropley, 2015).

The reader should pay attention to the last 4 words in the last paragraph: ‘to produce creative acts,’ which emphasize the goal of the *creative process models,* which are also known as *creative problem-solving models.* These models are different from the *problem-solving models*—notice that the word ‘creative’ in the front of the ‘problem-solving models’ phrase is missing. The creative problem-solving models are meant for solving *creative problems.* In these problems, no obvious solution is known, and that the solution can not be reached by merely following a set of well-defined rules and/or formulas. When having such problems, creative problem-solving models should be the way to go. Otherwise, the typical problem-solving models will be a good option. However, it is unknown if following the typical problem-solving models will be of any help when solving creative problems.

Many models are proposed in the literature for the creative process; some are based on the *efficacy, theoretical approach* while others are based on the *pragmatic, practical approach* (Isaksen & Treffinger, 2004; Murdock & Puccio, 1993; Sternberg & Lubart, 1996). The main goal of the first set of models, i.e., those that followed the *efficacy,* *theoretical approach*, is to *understand creativity*, while the main goal for the second set of models, i.e., those that follow the *pragmatic, practical approach*, is to *develop creativity* (Murdock & Puccio, 1993; Sternberg & Lubart, 1996). Given their nature, the second set of models usually suffer from low validity compared to the first set of models (Murdock & Puccio, 1993; Sternberg & Lubart, 1996). The readers should keep this efficacy/pragmatic approach concept in their minds when going through the list of the creative process models. By doing so, many of the superficial conflicting issues will soon be resolved.

In this section, two of the most popular models will be introduced, namely, Wallas Model, introduced in Section 3.6.3.1, and Osborn-Parnes Creative Problem-Solving Model, introduced in Section 3.6.3.2. A list of other models will be only listed, i.e., without introduction, in Section 3.6.3.3. A discussion of the Wallas Model and Osborn-Parnes Creative Problem-Solving Model in light of the generic creative problem-solving process will be given in Section 3.6.3.4.

3.6.3.1 Wallas Model

In his book *The Art of Thought*, Wallas (1926) outlined the process of creative thought[25]. Wallas (1926) claimed that the creative process is a cyclical process that consists of 4 stages: *preparation*, *incubation*, *illumination*, and *verification*. During the *preparation* stage, the individual is expected to research the problem to gain a deeper understanding. In this stage, the individuals' knowledge about the problem domain and their general knowledge will be of immense help. In the next stage, i.e., the *incubation* stage, the individual is supposed to play with the problem in their head for a while by looking at the problem from different perspectives. In this stage, the divergent abilities of the participant play a significant role. The third stage, i.e., the *illumination* stage, is where the solution (or solutions) emerges and becomes apparent. It will be helpful in this stage that the individual gets involved in activities that activate/stimulate their subconscious mind, such as taking a short walk, taking a shower, or doing some sort of meditation; such activities will allow the connections between the far-apart ideas to form and new

[25] According to Rhodes (1961), the creative process proposed by Wallas (1926) was based on the answer that the German physiologist and physicist Hermann von Helmholtz gave as an answer to the request that was made to Helmholtz in his 70th birthday party to analyze his thought process.

ideas to appear. The last stage before repeating the cycle is the *verification* stage, where the obtained solution (or solutions) is inspected for its applicability to the problem. In this stage, the individuals' divergent thinking abilities play a significant role.

3.6.3.2 Osborn-Parnes Creative Problem-Solving Model

Osborn (1953)'s work titled *Applied Imagination: Principles and Procedures of Creative Problem Solving* was based on the creative problem-solving (CPS) model. With the help of Parnes (1967), the CPS model was born 14 years later (Treffinger, 1995). The model consists of 5 stages: *fact-finding*, *problem finding*, *idea finding*, *solution finding*, and *action finding*. During the *fact-finding* stage, the individual needs to gather enough information about the problem. The second stage of the model is the *problem-finding* stage, where the problem is investigated more deeply to uncover the "real" problem that the individual needs to focus on. After identifying the "real" problem, the *idea-finding* phase takes place. During this phase, many potential solutions to the problem are sought. After generating many potential solutions to the problem, the best options are identified in the *solution finding* stage. After identifying the best options, the *action-finding* stage starts where an implementation plan for the best solution (or solutions) is worked and executed.

The CPS model evolved many times, and there are different varieties of it. In their paper titled *Celebrating 50 years of Reflective Practice: Versions of Creative Problem*

Solving, Isaksen and Treffinger (2004) discussed the evolution that the CPS went through till reaching CPS Version 6.1™ maintained by the Creative Education Foundation[26]. In addition to the 5 stages in the original CPS model, the CPS Version 6.1™ model includes an extra stage, *mess-finding* stage before the fact-finding step (Treffinger, 1995). In the mess-finding stage, the individual is expected to describe the basic, general idea that the problem is focusing on.

3.6.3.3 Others

Some of the other creative problem-solving models found in the literature are Campbell (1960)'s Blind-Variation and Selective-Retention Model of Creative Thought, Simonton (1988)'s Creative Process Model based on Chance-Configuration Theory, (Barron, 1988)'s Psychic Creation Model, Rossman (1931)'s Creativity Model, Osborn (1953)'s Creative Thinking Model, and Kobler and Bagnall (1981)'s Universal Traveler Model.

3.6.3.4 Discussion

The generic creative thinking process entails 3 distinct stages: problem-understanding stage, divergent-thinking stage, and convergent-thinking stage. During the problem

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[26] www.creativeeducationfoundation.org

understanding stage, the individual seeks more clarity about the problem by looking at it from different perspectives and engaging the subconscious mind. In the divergent thinking stage, the individual, alone or in a group, should focus on merely generating as many potential solutions as possible without paying attention to the implementation details or the validity of these solutions. In the convergent stage, the generated potential solutions are evaluated for their applicability to the problem, and the best one (or ones) is selected. The following paragraph will map Wallas Model and Osborn-Parnes Creative Problem-Solving Model to this generic creative thinking process.

The first two stages of the Wallas Model, i.e., the preparation and incubation stages, fall under the problem understanding phase. In contrast, stage 3, i.e., the illumination stage, falls under the divergent-thinking stage, and the last stage, i.e., the verification stage, falls under the convergent-thinking stage. Similarly, the first two stages of the Osborn-Parnes Creative Problem-Solving Model, i.e., the fact-finding and problem-finding stages, fall under the problem understanding stage. In contrast, stage 3 of the model, i.e., the idea-finding stage, represents the divergent-thinking phase. Stage 4 and 5, i.e., the solution finding stage and action finding stage, represent the convergent-thinking phase.

3.6.4 Mental Models

Unlike process models, metal models focus on the cognitive processes (mental operations) that occur when generating creative solutions, i.e., the patterns of thought and information processing habits in the brain while generating a creative act (Simonton, 1988). In this section, one metal model, namely, Honing Theory, will be introduced in Section 3.6.4.1, followed by a discussion in Section 3.6.4.2.

3.6.4.1 Honing Theory

The honing theory (Gabora, 2017) explains how creative ideas form in the creator's head. The theory states that creativity is a byproduct of the mind that, when it detects gaps or inconsistencies in the environment, tries to consider these gaps and inconsistencies from different perspectives to find a form that fits with their world models. Looking to these gaps and inconsistencies from different perspectives may induce restructuring their representations which "may involve recoding the problem such that new elements are perceived to be relevant" (Gabora, 2017, p. 36). This phenomenon produces what is called *psychological entropy* (Hirsh, Mar, & Peterson, 2012). The psychological entropy concept states that self-organizing systems such as the mind are always in continual dialogue with their environment to keep their internal uncertainly level (psychological entropy) at a manageable level.

3.6.4.2 Discussion

Given the extreme complexity of creativity, a complete description of the neurobiological basis of creativity is still not fully understood (Boden, 2013; Simonov, 1997). A good reference that investigates the relationship between creativity and cognitive processes is the edited volume by R. E. Jung and Vartanian (2018) titled *The Cambridge Handbook of the Neuroscience of Creativity.* The volume contains a collection of articles that investigate the relationship between creativity and (a) attention and imagination, (b) memory and language, (c) cognitive control and executive functions, and (d) reasoning and intelligence.

3.6.5 Ecological Models

The ecological models focus on studying the factors that affect the overall creative behavior: positively or negatively; partially or entirely; on the individual, group, organization, or societal level. These models treat creativity as a system and highlight the interactions between the different elements of creativity. In this section, two models will be introduced: Componential Framework of Creativity (Section 3.6.5.1) and Csikszentmihalyi Integrated Model of Creativity (Section 3.6.5.2), followed by a discussion in Section 3.6.5.3.

3.6.5.1 Componential Framework of Creativity

After recognizing the need for the focus on the cognitive-abilities approach when researching and building theories for creativity and not only the personality approach, Amabile (1983) proposed the componential framework of creativity. The framework, as shown in Figure 34, outlines the creative process and how it gets affected by the interaction of 3 components related to the creative individual (domain-related skills, creativity-related processes, and intrinsic task motivation) and another component related to the social environment within which the individual lives. The framework assumes that the creative work generated by any individual is a function of these 4 components, i.e., if any of them change, the creativity of the produced work changes.

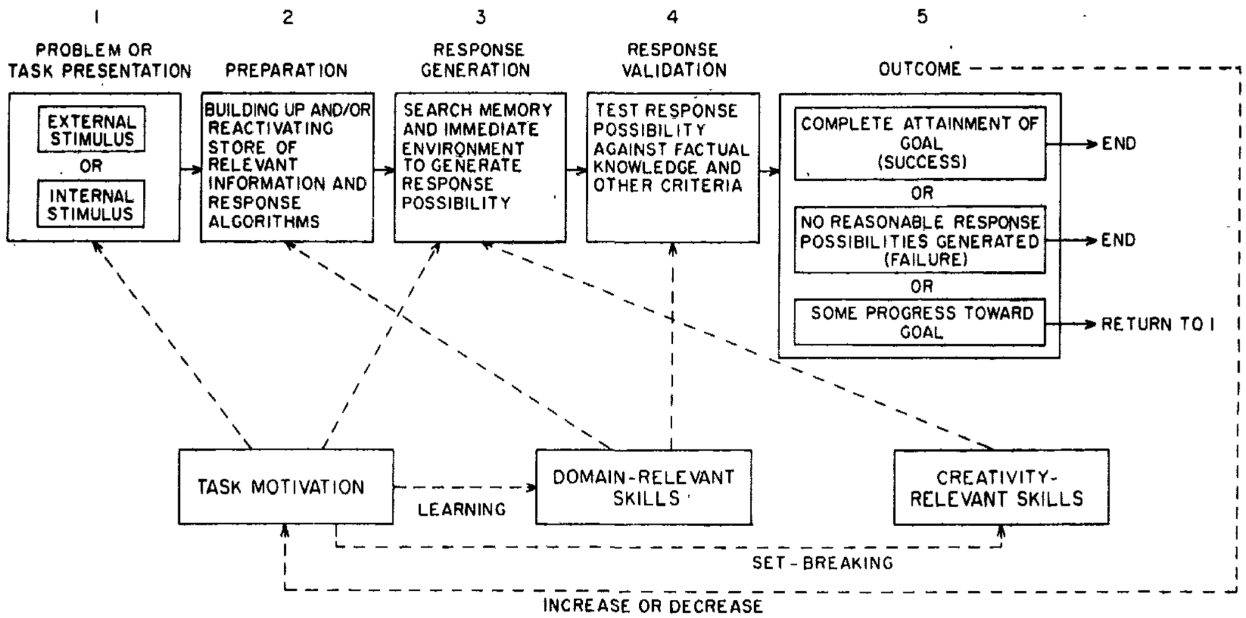

Figure 34: The Componential Framework of Creativity proposed by Amabile (1983). Dashed lines indicate the influence of particular factors on others. Solid lines indicate the sequence of steps in the process. Only direct and primary influences are depicted in the figure.

3.6.5.2 Csikszentmihalyi Integrated Model of Creativity

In his proposed model, Csikszentmihalyi (1988) emphasized that creativity is not a mere logical (structural) process but has an energetic side. The energetic side of creativity considers the individual's wishes, motives, affects, and goals and that the creative act is an interaction between the logical process and these energetic components. When outlining the energetic side of the model, Csikszentmihalyi (1988) considered 4 components:

(a) the level of interest the individual has toward the field in which they are working, (b) the level of perseverance the individual is willing to put into expanding the boundaries of the field, (c) the willingness of the individual to question the accepted formulation of the domain, and (d) the social environment within which the individual life which plays a role in either supporting or hindering the creative process of the induvial.

3.6.5.3 Discussion

The ecological models of creativity are also known as systems models of creativity because they focus on the larger ecosystem in which creativity emerges (Montuori, 2011). These models study creativity in its environment and assume that studying the components of creativity separately cannot help understand creativity phenomena as assumed by the reductionists (Montuori, 2011). Both the Componential Framework of Creativity and the Csikszentmihalyi Integrated Model of Creativity consider the systemic and emergent properties of the different components of creativity, i.e., the interaction between the characteristics of the individual and the environment within which they work.

3.7 Overall Discussion of All Categories of Models

As explained in detailed in Section 3.6, creativity models can be classified into five main categories: Level Models, Thematic Models, Process Models, Mental Models, and

Ecological Models. The Level Models are concerned with classify creativity into different types and levels, e.g., little-c creativity and Big-C creativity. Thematic Models are concerned with organize the landscape of creativity research into different themes, e.g., process, person, and press. Process Models focuses on explaining the creative process, i.e., the steps involved in producing a creative act. Similar to the Process Models, Mental Models focuses on mental process that goes into the head of the creator when the production of the creative act occurs. Ecological Models are concern with investigating the relationship between the creative performance and the numerous factors affecting it.

The creativity framework within which the above findings are reported is that a creative act must be at least (a) *novel*, unprecedented in the society in which the act was introduced and is not copied from somewhere else by the creator, and (b) *useful*, to some degree, to the society in which it was introduced judged by the society itself immediately or after a while (Batey, 2012; Craft, 2001; D. H. Cropley & Kaufman, 2012; Lee et al., 2012; Mayer, 2014; Mumford, 2003; Runco & Jaeger, 2012; Said-Metwaly et al., 2017a; Zeng et al., 2009). Regardless of the widespread agreement that novelty and usefulness represent the bare minimum requirements for an act to be labeled creative, the exact definition for novelty and usefulness is debatable (Batey, 2012; Batey & Furnham, 2006; Runco & Jaeger, 2012).

3.8 Opportunities and Future Work

Most of the opportunities reported in Section 2.7.1 of Chapter 2 regarding the article finding strategy and the article selection strategy used are applicable in this chapter, i.e., finding and selecting articles to be part of the analysis. Given the nature of the posed research questions in this chapter, no rigorous systematic strategy was followed. Hence, a more rigorous search strategy like the one explained in the methodology section (Section 2.5) of Chapter 2 should be considered in the future.

4
CREATIVITY FACTORS

"The ultimate knowledge is to know that you don't know."

—unknown

4.1 Introduction

The goal of this chapter is to answer the research question "What factors affect creativity?" However, like the proliferation of research available around creativity models, which were covered in Chapter 3, the research around the factors that affect creativity is also massive. To demonstrate how vast this topic is, a search with the terms 'creativity factors' was performed on fourteen academic databases, namely, Knovel, ASME Digital

Collection, AIAA Electronic Library, PsycTESTS, ERIC, PsycARTICLES, JSTOR, IEEE Xplore, GEOBASE, ACM Digital Library, PsycINFO, Web of Science, Compendex, and Google Scholar. Figure 35 shows the results of the search performed under three different criteria: (a) in the field title only, (b) in either the title or the abstract fields, and (c) in any field. Although no systematic literature review was performed to eliminate duplicate articles add relevant ones, the results indicate how overwhelming this amount of literature could be for any researcher approaching creativity.

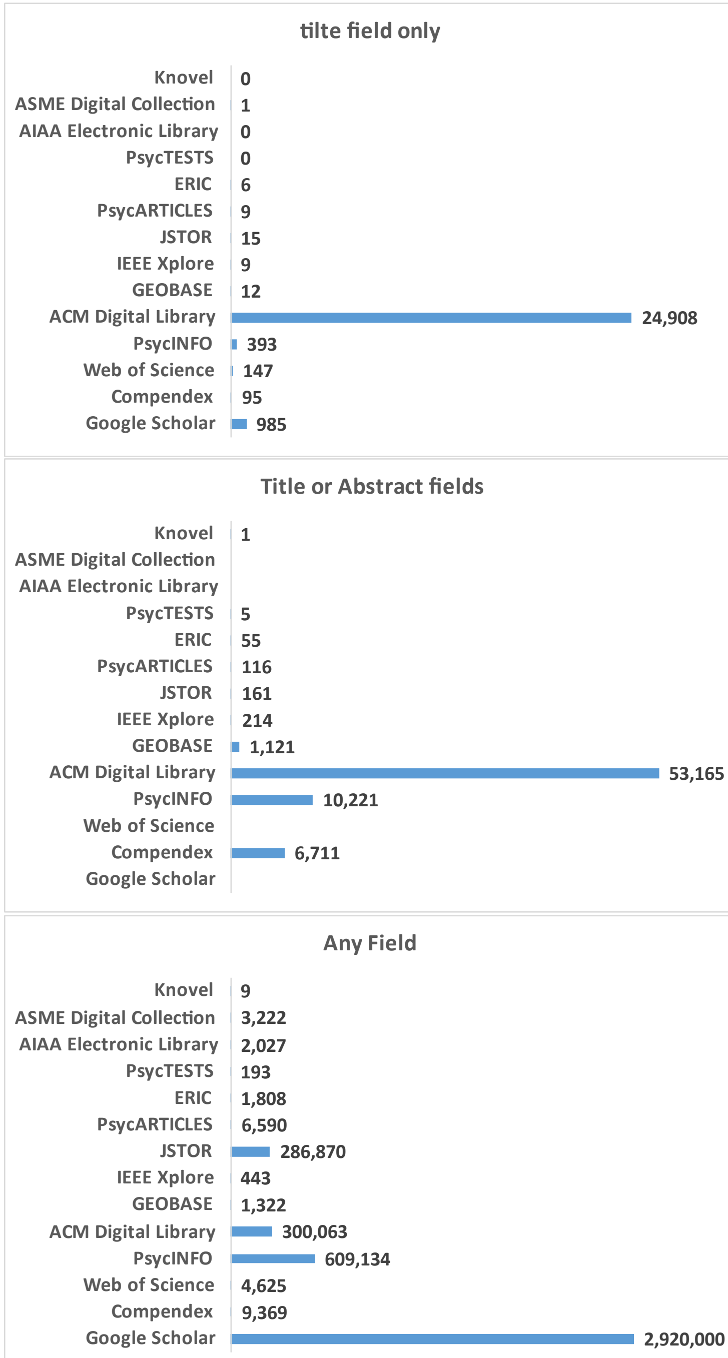

Figure 35: The number of results obtained when searching multiple databases for the term 'creativity factors' using different fields, i.e., the title field (top), the title or abstract fields (middle), and any field (bottom). The entries without values in the top-right figure, i.e., Title or Abstract fields, indicate that the database does not support searching the abstract field or does not support either searching terms in the title or abstract, i.e., searching using the OR operator is not supported.

4.2 Motivation

The motivation behind this chapter is to provide creativity researchers, especially those who are preparing to enter the field, with a roadmap that they can use to navigate the vast literature landscape of creativity factors. Having such a roadmap is expected to push the creativity research forward since it will provide a clearer understanding of what topics are being focused on currently and what gaps exist that need to be addressed. The roadmap will also help determine the relevant category into which any creativity work investigates the factors that affect creativity fall. Eventually, such a roadmap is expected to push the creativity research forward, as evident in the history of sciences (Rhodes, 1961)[27]. As Rhodes (1961) puts it: ‘every branch floundered until facts were organized and classified’ (p. 309).

4.3 Chapter Outline

The rest of the chapter will follow the same organization of Chapter 3 where (a) the research questions that ought to be answered are posed in Section 4.4, (b) the methodology used to answer the posed research question is explained in Section 4.5, (c)

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[27] See footnote 11 on page 62 for a discussion of the importance of classifications in advancing sciences.

the results to the posed research questions and the discussion around each segment of the results are reported in Section 4.6, and (d) the opportunities for taking the current work to the next level are outlined in Section 4.7.

4.4 Research Questions

The main research question that will be answered in this chapter is RQ3: What factors affect creativity? The question will be tackled by answering the following sub-research questions, as also shown in Figure 2:

- RQ3.1: What categories of creativity factors exist?
- RQ3.2: How do these categories relate to each other?
- RQ3.3: What factors fit under each category?

4.5 Methodology

This section explains the process used to answer the posed research question in Section 4.4. The process starts by building an overall understanding of the relevant literature currently exists around the creativity factors. This step will help answer RQ3.1: What categories of creativity factors exist? and RQ3.2: How do these categories relate to each other?. To help in building such an overall understanding, visual mapping techniques such as mindmaps will be used. Such maps are expected to go through multiple iterations before extracting the categories from them.

After building an overall understanding of the literature, selected papers collected during the corpus building step of creativity definitions and that study the effect of some factors on creativity will be used to indicate to which category each factor belongs. The process will be performed systemically by adding extra fields in the existing corpus for each encountered factor in the relevant papers. Also, if any factor was referred to using different names, the alternative names will be noted.

4.6 Results & Discussion

The answer to RQ3.1: What categories of creativity factors exist? and RQ3.3: What factors fit under each category? will be simultaneously answered in Section 4.6.1. In contrast, the answer to RQ3.2: How do these categories relate to each other? will be reported in Section 4.6.2.

4.6.1 RQ3.1: What categories of creativity factors exist? and RQ3.3: What factors fit under each category?

After carrying out the process outlined in Section 4.5, the following sets of factors emerged: (a) factors related to the individuals, which will be discussed in Section 4.6.1.1,

(b) factors related to the environment where the individual live or work which will be addressed in Section 4.6.1.2, and (c) factors related to the approaches and tools used to solve creative problems which will be covered in Section 4.6.1.3. Section 0 will be used to discuss the reported sets of factors in the previous sections.

4.6.1.1 Personal Characteristics

This section covers the characteristics that define the individual's personality (identity) and are believed to affect creativity. From a biological perspective, these characteristics can be classified into two sets: biological and non-biological characteristics.

Biological Characteristics. The biological characteristics represent the set of factors that the individual is born with and are impossible, or exceedingly difficult, to change. This set includes factors such as (*chronical*) *age* (Binnewies, Ohly, & Niessen, 2008; Price & Tinker, 2014; Sternberg & Kaufman, 2018; Wu, Cheng, Ip, & McBride-Chang, 2005), *sex/gender* (Baer & Kaufman, 2008; Kaufman, 2006; Stoltzfus, Nibbelink, Vredenburg, & Hyrum, 2011), and *race/ethnicity* (Kaltsounis, 1974; Kaufman, 2006; Lynn, 2008; Pretorius, Millard, & Kruger, 2005).

Non-biological Characteristics. The non-biological characteristics include all the factors that the individual has control over and can be changed even if the change is challenging. This set includes factors such as *domain-specific knowledge and experience*

(P.-S. Huang, Peng, Chen, Tseng, & Hsu, 2017; Kilgour, 2006; Rietzschel, Nijstad, & Stroebe, 2007), *general knowledge and experience* (Batey, Furnham, & Safiullina, 2010; Belski, Skiadopoulos, Aranda-Mena, Cascini, & Russo, 2019; Boden, 2011), *intrinsic motivation* (de Jesus, Rus, Lens, & Imaginário, 2013; Eisenberger & Shanock, 2003; Hennessey & Amabile, 1998), *general personality* (Aguilar-Alonso, 1996; Feist, 1998, 2010), *creative personality* (Helson, 1996; Martinsen, 2011; Selby, Shaw, & Houtz, 2005), *creative self-efficacy* (Haase, Hoff, Hanel, & Innes-Ker, 2018; Richter, Hirst, van Knippenberg, & Baer, 2012; Tierney & Farmer, 2002), *creative potential* (DiLiello & Houghton, 2008; Guilford, 1966; Sternberg, Grigorenko, & Singer, 2004), *intelligence* (Kaufman & Plucker, 2011; Sternberg, 2003; Sternberg & O'Hara, 2000), and *mood/affect* (Amabile, Barsade, Mueller, & Staw, 2005; Bledow, Rosing, & Frese, 2013; Davis, 2009; Kaufmann, 2003a; Russ, 1993).

4.6.1.2 Environmental Characteristics

Environmental characteristics represent all the factors surrounding the individual and are usually outside of the individual's control. The environmental factors can be divided into 3 sets: social, physical, and virtual. The social set includes factors such as *home* (Domino, 1979; Pugsley & Acar, 2020; Y. Tang, Huang, & Wang, 2017), *friends*[28]/*peers*[29] (Madjar, Oldham, & Pratt, 2002; Nouri, Erez, Lee, Liang, Bannister, & Chiu, 2015; Stone, 1980), *school/work* (Amabile, Conti, Coon, Lazenby, & Herron, 1996; Moran, 2010; West, 2000), *culture* (Kwan, Leung, & Liou, 2018; Ludwig, 1992; Rudowicz, 2003), and *society* (A. Cropley, 2006; Csikszentmihalyi, 2014a; Society, 1995). The physical set includes factors related to the design of the physical environment within which the individual works (Kallio, Kallio, & Blomberg, 2015; Kristensen, 2004), such as the existence of the natural elements (Chulvi, Agost, Felip, & Gual, 2020) and cues (Friedman & Förster, 2001). Similar to the physical set, the virtual set includes factors related to designing the virtual environment with which the individual interacts (Fleury, Blanchard, & Richir, 2021).

4.6.1.3 Approaches and Tools

The individuals' set of approaches and tools to solve a given creative problem may affect creativity. When correctly followed, approaches such as *Wallas 4-Stage Model* proposed by Wallas (1926) (see Section 3.6.3.1 for details) and *Osborn-Parnes Creative Problem-*

[28] Friends here means those who are in a proximity to the individual.

[29] Peers here means those who are not in a proximity to the individual but share some commonalities with the individual.

Solving Model proposed by Parnes (1967) (see Section 3.6.3.2 for details) can help individuals to generate creative solutions. Tools[30] such as *Brainstorming* (Osborn, 1953, 1963), *Synectic* (Wilson et al., 1973), *Morphological Chart* (Cross, 2021), *TRIZ* (Altshuller, 2000), and *Six Thinking Hats* (de Bono, 1956), when used within the appropriate approach, can facilitate the generation of creative ideas.

There are so many factors that can positively or negatively affect creativity. The reported sets of factors in the previous sections of this chapter represent only a classification of these factors. No effort has been placed on considering how each factor enhances or inhibits creativity and how these factors affect each other, e.g., how social environmental characteristics influence individuals' non-biological characteristics (psychosocial factors).

4.6.2 RQ3.2: How do these categories relate to each other?

Figure 36 visually depicts a simplified model of the possible relationship between the distinct categories of factors outlined in Section 4.6.1. Since people do not live in isolation,

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[30] The tools are different from the creative processes—they help their users to recognize and tap into the creative process (D. H. Cropley, 2015). In other words, the tools are just techniques and hence we need a process to tell us when to use which in order to generate creative ideas effectively (D. H. Cropley, 2015).

their personal characteristics are expected to get affected by the characteristics of the environment in which they live. This relationship is shown by the directed arrow from the circle representing the environment characteristics factor to the circle representing personal characteristics factor. The relationship between the approaches and tools used to solve the problem is shown via a mediating effect between personal characteristics factors and creativity. In other words, the choice of a particular approach and tool can influence the degree to which the individual produces creative solutions. The relationship is shown by a directed arrow that extends from the circle representing the approaches and tools factor and points to the arrow that goes from the circle representing the personal characteristic factor to the circle that represents creativity.

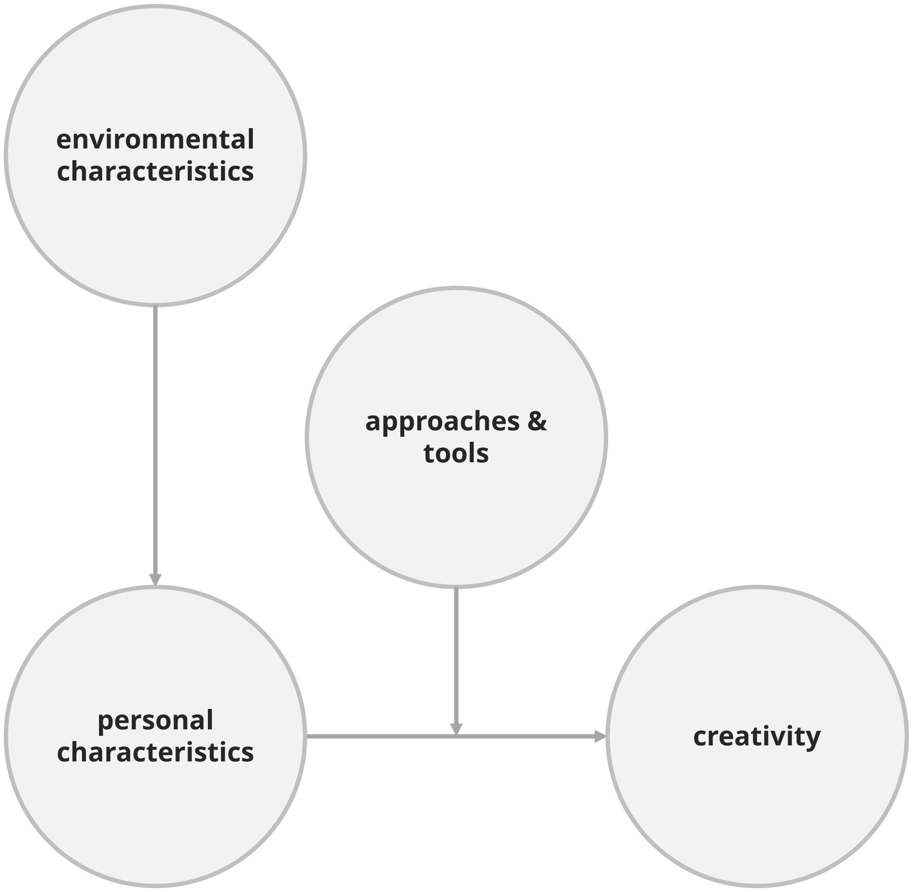

Figure 36: A visual depiction of the possible relationship between the various categories of factors that are reported to affect creativity.

Although not shown in Figure 36, the environmental characteristic can impose restrictions on the approaches and tools used to solve a given creative problem. Therefore, a direct link that extends from the circle representing the environmental characteristics factor to the circle representing the approaches and tools factor can be drawn. Similarly, the environmental factors can play a significant role in determining if an act is deemed to be hold the “creative” label and hence a direct link that extend from the circle representing the environmental characteristic factor to the circle representing the creative act can be drawn.

Like the approaches and tools factor, the environmental characteristics factors can play role in helping the individual to produce a creative act. Hence, the environmental characteristics not only can have a direct effect on the personal characteristics, as shown by the direct link that extend from the circle representing the personal characteristics factor to the circle representing the personal characteristic factor, but also can influence the creative process by enabling (or hindering) the individual to produce creative act. To represent this relationship, a directed arrow that extends from the circle representing the environmental characteristics factor and points to the arrow that goes from the circle representing the personal characteristic factor to the circle that represents creativity can be drawn, like the arrow used to show the effect of the approaches and tools factor.

The model linking the distinct categories of factors assumed to affect creativity reported in Section 4.6.2 represents a simplified ecological model (see Section 3.6.5 for more information about the ecological models). Comparing it to the Componential Framework of Creativity (CFC, Amabile, 1983) discussed in Section 3.6.5.1, the three components related to the individual characteristics, i.e., domain-related skills, creativity-related processes, and intrinsic task motivation, that the CFC is addressing is represented by the personal characteristics factor of the model proposed in Section 4.6.2. Both the CFC model and the proposed model share agreed on the effect of the social environment on the individual—the CFC model used the term ‘social environment.’ In contrast, the proposed model in Section 4.6.2 used the term ‘environmental factors.’

When comparing Csikszentmihalyi Integrated Model of Creativity (CIMC, Csikszentmihalyi, 1988) discussed in Section 3.6.5.2 with the proposed model in Section 4.6.2 of this chapter, the proposed model integrates the 3 components related to the individual, i.e., interest, perseverance, and willingness to question the accepted formulation, proposed by CIMC into a single factor named individual characteristics. Both the proposed model in Section 3.6.5.2 and CIMC consider the effect of the social environment on the creativity of the individual.

4.7 Opportunities and Future Work

Few points need to be considered to take this chapter to the next level. First, a more systematic approach can be considered when approaching the literature. Taking a more systematic approach with the forward and backward citation search will yield more robust findings—the new process will ensure that all the representative literature is included and that the findings are reproducible. Second, all the factors investigated in this chapter are extracted from the generic literature. It might be beneficial also to consider only the engineering literature to highlight the factors that affect the creativity of engineers then comparing the findings with the results reported in this chapter.

5
CREATIVITY IN ENGINEERING

"Creativity is the key to education in its fullest sense and to the solution of mankind's most serious problems."

—J. P. Guilford

5.1 Introduction

As mentioned in Chapter 4, many factors can affect creativity; some foster it, and others inhibit it. This section, i.e., the Introduction, will briefly present the set of factors investigated in a study that will be described afterward in this chapter. Two broad categories of factors will be considered, namely, personal characteristics (Section 5.1.1) and environmental factors (Section 5.1.2). After presenting the factors, this section will introduce crowdvoting in Section 5.1.5, a practice used to evaluate the substantial number of responses obtained from the participants during the study. This section will also introduce the techniques used to measure the cortical activity exerted by the participants while performing the tasks given to them. The cortical activities that will be considered are electroencephalography (EEG) and Event-Related Potential (ERP). The introduction of these techniques will appear in Section 5.1.4. Toward the end, a discussion of why engineers need to be studied separately from non-engineers is given in Section 5.1.5.

5.1.1 Personal Characteristics

This section introduces the set of personal characteristics that are either (a) reported to affect creativity, such as knowledge and experience and/or (b) commonly taken into consideration when conducting (creativity) research such as age, gender, and race.

Biological Factors. The meaning of the biological factors used here is those that the person has no control over. Three factors will be considered in the study outlined in this chapter: age, gender[31], and race. These factors represent commonly investigated factors in research and were found to affect various aspects of life, including creativity.

The study of the effect of gender on creativity has been extensively studied. However, the findings are not consistent; some studies reported differences in creativity based on gender; however, others did not reach such conclusions. Baer and Kaufman (2008) reviewed research on gender differences in creativity when measured (a) objectively[32] via tests, (b) subjectivity via self-assessment, assessment by others, and personality-style assessments, and (c) historically via accomplished achievements. In regards to the studies that use tests to assess creativity, Baer and Kaufman (2008) cited 37 papers where no gender differences were found, 4 papers where males were found to

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[31] Although the term “gender” has been used here as a biological factor, it is more accurate to use the term ‘sex’ instead since the term ‘gender’ represents sexuality from the point view of the person, society, and culture; see Archer and Lloyd (2002), Deaux (1985), Delphy (1993), Lips (2020), and Marini (1990) for an extended discussion.

[32] Purely objectively measuring creativity may not be possible because at one point throughout the process a subjective decision normally is made; see Onwuegbuzie and Leech (2005) and Johnson and Onwuegbuzie (2004) for an interesting discussion about the debate between the quantitative and qualitative research paradigms and why some objectivity-claims measures are not so.

score higher, 9 papers where females were found to score higher, and 31 papers where mixed results[33] were observed.

In regards to assessing creativity using self-assessment, Baer and Kaufman (2008) cited 3 papers where no gender differences were found and two papers where gender differences were found but only on a small number of dimensions measured by the assessment test. For example, after asking 3,553 individuals to rate themselves on 56 domains of creativity Kaufman (2006) found that there were significant gender differences in 43 of the dimensions (domains)— males rated themselves higher in 28 dimensions (domains) while females rated themselves higher in the other 15 dimensions[34] (domains).

The study of age, gender, and race in the realm of the creative performance investigated in the study, which will be later outlined in this chapter, will take the

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[33] A paper reporting mixed results means that the paper either (a) includes more than one study and that some of the studies found that males tend to score higher while others found that females tend to score higher, (b) include one study but multiple dimensions were used to measure creativity and males exceed females on some dimensions while females exceed males on others, or (c) mix of case (a) and case (b), i.e., includes more than one study that measure creativity on multiple dimensions and that males score higher in some studies on some dimensions and females score higher in other studies on other dimensions.

[34] In most cases, gender differences that were observed through self-assessment tests are associated with gender stereotypes (Baer & Kaufman, 2008).

inclusive approach. In other words, any evidence of significant differences in creativity based on the factors mentioned above, i.e., age, gender, and race, that may be found in the study shall only be used to deliver tailored, personalized designs, solutions, and experiences for each group based on their needs, and it shall not be used for exclusion. The rest of this section, i.e., Section 5.1.1, introduces a set of factors that individuals typically have control over and can be changed to some extent.

Knowledge and Experience. Coupled with intellectual flexibility and openness, deep knowledge and experience in the problem subject area can significantly impact creativity (Corazza & Agnoli, 2018; Kraft, 2005; Webb et al., 2018). However, such deep knowledge and experience could turn into a barrier when not accompanied by flexibility and openness (Bourgeois-Bougrine, Richard, Burkhardt, Frantz, & Lubart, 2020)—what Pinker (2014) calls the "curse of knowledge[35]."

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[35] The "curse of knowledge" is also known as *mind blindness*, *egocentrism*, and *hindsight* bias. People suffering from this problem have high *latent inhibition*, a strategy employed by the brain to filter information that has been shown by experience to be less important from the wealth of data that stream to our head every second through our sensory system. A high latent inhibition means more information is being filtered while a low latent inhibition means less information is being filter and this state, i.e., the low latent inhibition, is often associated with psychosis. For extended discussion about latent inhibition, see Lubow (1973, 1989) and how it is related to creativity, see Carson, Peterson, and Higgins (2003).

In her book *InGenius: A Crash Course on Creativity*, Seelig (2012) claims that, along with imagination and attitude, knowledge constitutes the internal combustion engine for creativity. Seelig (2012) states that knowledge is the toolbox for imagination, imagination is the catalyst for forming new ideas, and attitude is the driver of the process. Plucker and Renzulli (1999) also found that creativity strongly correlates with individuals' knowledge, abilities, attitudes, and personality traits. Therefore, it is very plausible to say that when children show poor creative performance, that could be due to the lack of experience and not creativity (Riga & Chronopoulou, 2014).

When defining creativity, Rhodes (1961) placed knowledge at the heart of the given definition. In simple terms, Rhodes (1961) stated that creativity is "the process of recognizing knowledge (general or specific knowledge), and of articulating that synthesis so that other people can understand the meaning" (p. 305). Similarly, when defining creative thought, J. W. Getzels and Jackson (1959) placed a big emphasis on knowledge—they described creativity as "directed, easily flexible, manipulation of knowledge in a wide variety of novel or original ways" (p. 46).

The knowledge and experience that the individual holds may need to expand multiple domains for the individual to produce a creative act, especially if the problem is a multidisciplinary one. In other words, if a creative solution is sought for a multidisciplinary problem, the individual needs to have a certain level of solid knowledge and experience in all disciplines that the problem is covering (Kraft, 2005). Often, this is not possible, especially in the current age where the problems are complex, multidisciplinary in nature, and above the individual capacity to be solved alone. Hence, tackling multidisciplinary problems needs a team with a diverse set of knowledge and experiences.

When considering the empirical research, there are contradicting results regarding the effect of knowledge on creativity—some showed a significant relationship between knowledge and creativity while others did not. Ibrahim (2012), in his doctorate dissertation, studied 55 students enrolled in a mechanical engineering design capstone course at Colorado State University. The students' creativity was measured at the beginning of the capstone course in Fall 2011 and the end of the course in Spring 2012. Using the grade point average as a measure for knowledge and the Torrance Tests of Creative Thinking (TTCT) Figural Form A as a measure for creativity, Ibrahim (2012) found no relationship between the student's knowledge and the creativity scores obtained on the TTCT test. Contrary to Ibrahim (2012)'s conclusion, Kershaw, Bhowmick, Seepersad, and Hölttä-Otto (2019) showed that knowledge obtained through the undergraduate curriculum has a longitudinal growth effect on creativity. The authors showed that creativity measured through the originality score assigned to ideas generated for a design problem, a garbage collection system, was higher for the advanced mechanical engineering students than beginners.

Personality. Personality can be defined as "the collection of intrinsic and extrinsic traits that may affect the behavior of an individual" (Abdullah, Omar, & Panatik, 2016, p. 178) As a behavior, creativity is influenced by a diverse set of personal characteristics (Abdullah et al., 2016; Barron & Harrington, 1981; D. H. Cropley, 2019; D. I. Jung, 2001). Treffinger (2009) tally more than 300 personal characteristics that are presumed to indicate creativity. Treffinger (2009) pointed out that no single set of these characteristics can differentiate the creative person[36]. Hence, it is no wonder that after analyzing 40 definitions of creativity, Rhodes (1961) found that personality emerges as a significant focus in these definitions.

Among this diverse set of personal characteristics associated with creativity, characteristics such as "broad interests, attraction to complexity, high energy,

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[36] Since there is no single set of characteristics that can be used to differentiate the creative person, Treffinger (2009) suggests that instead of asking *how creative you are?* is to ask, *how are you creative?*—putting the "is" in the front yields a more powerful question!

independence of judgment, autonomy, intuition, self-confidence, ability to resolve antinomies or to accommodate opposite or conflicting traits in one's self-concept, and a firm sense of self as creative" represent the core personal characteristics. These characteristics continuously correlate with creative acts across different domains (Barron & Harrington, 1981, p. 453).

Creative Self-Efficacy. Creative self-efficacy is a form of self-efficacy that represents one's belief in themselves to perform a task creatively[37] (Beghetto & Karwowski, 2017; Farmer & Tierney, 2017; M. Tang, Hu, & Zhang, 2017; Tierney & Farmer, 2002). Creative self-efficacy is positively related to creativity and is a significant predictor (Pretz & Nelson, 2017). Creativity is a self-actualizing trait and not an exceptional talent (Richards, Kolva, Atkin, Cheatham, Crocker, Ockuly, Goslin-Jones, Jones, Kasian, Kenny, & Smith, 2011).

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[37] *Creative self-belief* (CSB) is the term under which *creative self-efficacy* (CSE); *creative metacognition* (CMC), the "beliefs based on combination of creative self-knowledge and contextual knowledge;" and *creative self-concept* (CSC), the "general beliefs about one's creative ability" fall (Beghetto & Karwowski, 2017, p. 3). These and other related beliefs constitute what Karwowski and Barbot (2016) call *creative identify* which plays "a key role in determining whether a person will engage in creative performance opportunities, sustain effort when faced with challenges, and ultimately, demonstrate higher levels of creative achievement" (Beghetto & Karwowski, 2017, p. 3).

Creative Potential. The generativity theory suggests that individuals have unlimited potential to be creative, though they may not know about such creative potential (Epstein, Schmidt, & Warfel, 2008; Runco, 2004; Vlasic & Devjak, 2017). When this latent *creative potential* appears as an act, it is referred to as a *creative performance* (see Section 5.1.3 for more information). Creativity tests measure creative potential and not creativity performance (A. J. Cropley, 2000; Riga & Chronopoulou, 2014). Hence, high scores on these tests do not guarantee that the person will behave creatively in the future (Riga & Chronopoulou, 2014).

5.1.2 Environmental Factors

Certain factors in the individuals' environment can affect their behaviors and hence their creativity performance. This section introduces two factors that were shown to influence creativity, namely, cues and task engagement.

Cues. Exposing individuals to other people's ideas can help stimulate their associations and lead them to generate more ideas (Perttula & Sipilä, 2007). It is no surprise, therefore, in the edited book *Creating Creativity: 101 Definition* by Aleinikov et al. (2000) that Alden B. Bow defined creativity as "Our unique abilities, when put together, naturally create something new … this is called creativity." (p. back cover). In the framework, *The Search for Idea in Associative Memory*, Nijstad, Stroebe, and

Lodewijkx (2002) suggest that the idea generation consists of two stages: a knowledge acquisition stage followed by an idea production stage. The knowledge acquisition stage is activated via a search cue formed in the short-term memory, which is used to probe the long-term memory and eventually activate an image (Perttula & Sipilä, 2007). Hence, exposing individuals to other people's ideas can serve as a search cue to activate the knowledge acquisition stage.

In three experiments, Dugosh, Paulus, Roland, and Yang (2000) showed that exposing people to ideas can help enhance their idea generation process. Dugosh and Paulus (2005) also showed that people exposed to many common ideas generated more ideas than those exposed to few unusual ideas.

In engineering design, Perttula, Krause, and Sipilä (2006) showed that students who were allowed to exchange ideas with others generated more ideas than those who were instructed to work individually[38]. Also, in the field of design-by-analogy where designers look at solutions from other domains for inspiration, Fu, Chan, Cagan, Kotovsky, Schunn, and Wood (2013) showed that exposing designers to 'far' analogies

[38] The authors, i.e., Perttula et al. (2006), however, concluded that the observed results, i.e., generating more ideas when exchanging ideas with others, is due to social facilitation rather than cue stimulation.

stimulated them to generate more creative ideas compared to those who were exposed to 'near' analogies. However, Fu et al. (2013) found out that 'very far' analogies can be harmful to the participants with a higher level of knowledge.

Task Engagement. Engagement is a complex construct that consists of cognitive, emotional, and behavioral components, and it has many connotations in our everyday life such as "involvement, commitment, passion, enthusiasm, absorption, focused effort, zeal, dedication, and energy" (Schaufeli, 2013, p. 15). Task engagement, therefore, refers to the relationship between the person and the task being performed, i.e., the level of engagement that the person went into when performing the task[39].

In the educational realm, research has shown that the student learning outcomes depend on the depth and quality of engagement in learning (Finn & Zimmer, 2012; Fredricks, Blumenfeld, & Paris, 2004; Hollingshead, 2018). Based on empirical findings, Tan, Lau, Kung, and Kailsan (2019) reported that the higher the students were engaged in the given tasks, the higher they self-rated their creativity. In the corporate world,

[39] Task engagement comes under *work engagement* which represents the relationship of the individuals with their work (Schaufeli, 2013). Work engagement in turn comes under *employee engagement* which represents the relationship of the individuals with their organizations (Schaufeli, 2013).

besides creativity, Aldave, Vara, Granada, and Marcos (2019) reported that engagement plays a significant role in bringing innovation when developing solutions.

5.1.3 Creative Performance

Contrary to the creative potential introduced in Section 5.1.1, which concerns the readiness of the individual to perform creative acts, the creative performance is concerns with the creative acts that the induvial has already performed. It is no surprise then that the creative potential is sometimes called *latent creativity* or *covert creativity*. In contrast, the creative performance is called *historical creativity* (H-creativity, Kaufmann, 2003b), *manifest creativity* (Golann, 1963), *demonstrated creativity* (Fishkin & Johnson, 1998), *eminent creativity*[40] (Richards, 1990), and *overt creativity*. When the creative act is only novel to the person who created it, i.e., countless people did the same creative act in the past; such creative act is referred to as *psychological creativity* (P-creativity, Boden, 2013).

[40] Eminent creativity is sometime reserved to refer to creative acts that yield some sort of a significant impact (Richards, 1990).

5.1.4 Cortical Activity

EEG. Electroencephalography (EEG) is one of the known neurological measures besides Positron Emission Tomography (PET) and functional Magnetic Resonance Imaging (fMRI) that are used to observe the brain activity of individuals while working on a given task (Luck, 2014; K. Sawyer, 2011). EEG has a high temporal resolution that can reach up to one millisecond or better (Luck, 2014). EEG measurements are based on the biological electrical potential, i.e., voltage, produced outside the brain and measured via the scalp, which is a fast process (Luck, 2014). On the other hand, PET and fMRI have a low temporal resolution which, at their best, are limited to several hundred milliseconds. This is because PET and fMRI measure the blood flow in the brain, which is a slow process (Luck, 2014).

Regarding spatial resolution, the case is the opposite; PET and fMRI have a high spatial resolution in the millimeter range while EEG has a low spatial resolution (Luck, 2014). Again PET and fMRI are based on blood flow which goes through every part of the brain, while EEG is based on the biological electrical potential produced outside of the brain and measured via the scalp (Luck, 2014). Since there is infinity many configurations of the sources that resulted in the measured biological electrical potential, EEG not only has a low spatial resolution but rather an undefined one (Luck, 2014).

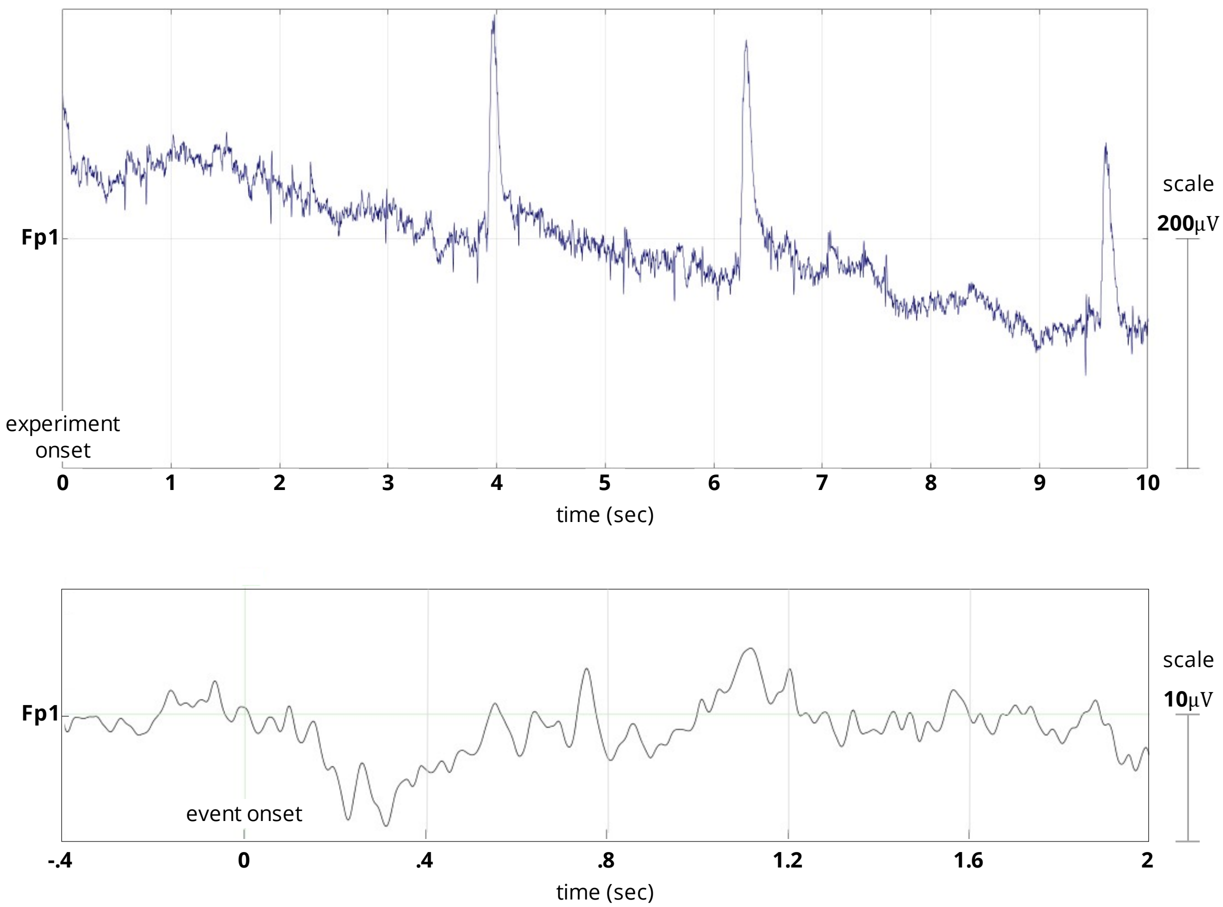

Figure 37: An example for EEG data (top) and ERP data (bottom) recorded on Fp1 electrode site for ten and two seconds, respectively.

Hence, locating the source of the biological electrical potential within a specific number of a millimeter is nearly impossible (Luck, 2014).

ERPs. ERPs stand for event-related potentials, and they represent "electrical potential[s] (voltage[s]) that [are] related to an event (usually a stimulus or a response)"

(Luck, 2014, p. 355). ERP data, which is computed from the EEG data, have a high signal-to-noise ratio, i.e., they are clean compared to EEG data which have a low signal-to-nose ratio, i.e., they are noisy. EEG data are continuous signals recorded throughout the session of the experiment. In contrast, the ERP data are time-locked signals to an event that occur multiple times during the experiment session. Figure 37 shows an example of EEG and ERP data.

Raw EEG signals have high amplitudes that range from 50-200 microvolts, μV, (Srinivasan, 2007) but usually range from .1-100 μV (Luck, 2014). The rest of the captured ranges of signals are usually considered noises (Luck, 2014). On the other hand, ERP signals have much smaller amplitudes, in the order of a few μV (Srinivasan, 2007). In the examples shown in Figure 37, the amplitude of the shown raw EEG signal goes up to 200 μV while the amplitude of the shown ERP signal goes only up to 10 μV, which is what was expected.

To measure most neurocognitive responses to specific sensory, cognitive, or motor events, some processing of the raw EEG via simple averaging technique or sophisticated time-frequency analysis is required (Luck, 2014). ERPs are elicited based on the former technique, i.e., the simple averaging technique, where the cortical responses to enough trials of the same event of interest are averaged. When having enough trials, the averaging will take care of all the other neural activities unrelated to the event of interest—they will cancel each other out (Luck, 2014).

EEG to ERP. Generating ERPs goes through a series of steps, and the process starts before even collecting the raw EEG data. Having a well-designed experiment suitable for ERPs is especially important; the events of interest should be repeated enough number of times, as mentioned above, and a brief period of no activity preceding the events of interest is crucial. The brief no-activity periods are used as the cortical baselines for the events coming after them. When the experiment is in place, and the raw EEG data are collected, a sequence of steps is necessary for eliciting the ERPs.

The first step that needs to be performed to elicit the ERPs is the *noise and artifact removal step.* This step includes filtering out all the frequencies outside the range that the brain typically generates, which is between .1 and 100 Hz (Luck, 2014). Also, since the 60 Hz frequency represents a noise signal from typical electrical devices in the surrounding environment[41], this frequency needs to be removed as well (Luck, 2014). Even after filtering out the noises mentioned above, the remaining signals are not all in response

[41] The EEG system is one of these devices.

to the shown event; some may represent eye blinks, and others may represent movements of facial muscles (Luck, 2014). These signals are called artifacts and need to be removed as well. After removing the noises and the artifacts, the EEG data will be ready for the ERP generation step.

In the *ERP generation step*, the EEG data get sliced into segments based on the events of interest in a process called *epoching* or *segmentation* (Luck, 2014). The epoching step is followed by the *averaging step*, where the EEG segments that belong to each group of the events of interest are averaged so that cortical activities not related to the events of interest are canceled out (Luck, 2014). This step results in raw ERPs. These raw ERPs need to be processed further, i.e., cleaned from any noises and artifacts—a process like what has been done on the raw EEG signal.

EEG Electrodes Placement System. The most popular system for deciding where to place the EEG electrodes on the scalp is the international 10-20 system (American Encephalographic Society, 1994). In its placement of the electrodes, the system considers the underlying area of the brain, specifically the cerebral cortex. The system was called so because the actual distance between any two adjacent electrodes is either 10% or 20% of the skull's total front-back or right-left distance (see Figure 38 for an illustration). The names of the electrodes start with 1-3 letters "to indicate the general brain regions, e.g., Fp for frontal pole, F for frontal, C for central, O for occipital, and T for temporal" (Luck, 2014, p. 6). The letters are followed by a number to indicate (a) "the hemisphere (odd for left and even for right)" and (b) "the distance from the midline (large numbers mean larger distances" (Luck, 2014, p. 8)). "A lowercase z is used to represent the number zero, which indicates that the electrode is on the midline" (Luck, 2014, p. 8).

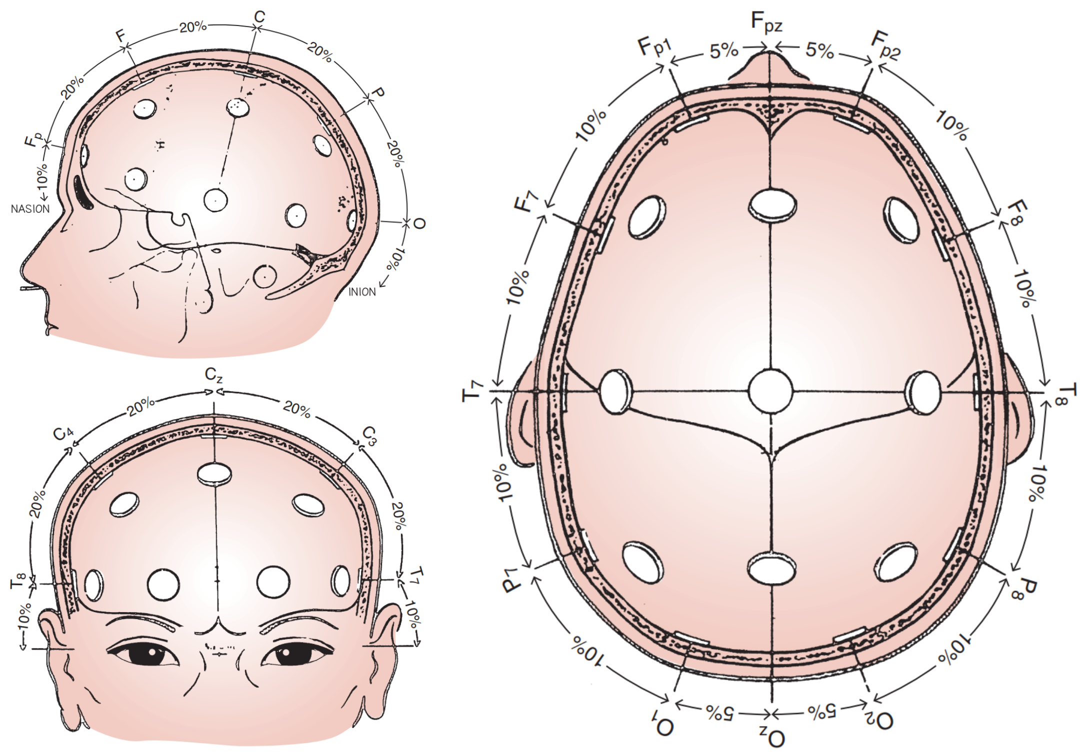

Figure 38: A visual illustration of the international 10-20 system for the placement of the EEG electrodes borrowed from Marcuse, Fields, and Yoo (2016).

ERP Components. The ERP waveforms consist of a sequence of positive and negative voltage deflections called *peaks*, *waves*, or *components* (Luck, 2014). The names of these components start with either P to indicate positive-going waves or N to indicate negative-going waves (Luck, 2014). Following the *N* or *P* letter, a number is used. The number indicates the component position in the waveform or the latency of the peak in milliseconds (Luck, 2014). For example, *P2* refers to the 2nd positive peak in the waveform, while *N170* refers to the negative peak happening at 170 ms. Components may also be given paradigm-based or function-based names such as the *error-related negativity* (which is observed when the subject makes an error) or the *no-go N2* (which is observed on no-go trials in go/no-go experiments) (Luck, 2014).

Two cognitive ERP components are of interest to the work in this chapter, namely, *P3*[42] and the *old-new probes paradigm*. The *P3* component peaks about 300 ms from the onset of the stimulus. It represents the level of unfamiliarity with the stimulus—the higher the peak, the higher the probability that the subject is unfamiliar with the stimulus (Luck, 2014). P3 component is largest on the *Pz electrode* site but can be observed on the other electrode sites as well (Luck, 2014).

The *old-new probe paradigm* is used to study the brain behavior during memory retrieval through a recognition task. The task studies probe stimuli that either match previously studies ideas (old probes) or do not match previously studies ideas (new probes). Two effects are expected to be observed when administering such experiments. First, a more negative peak between 300 to 500 ms from the onset for new probes

[42] According to Luck (2014), P3 was originally called P300 when it was discovered by Sutton, Braren, Zubin, and John (1965).

compared to the old probes with a maximal peak happening at the *midline frontal electrode* sites, namely, AFz, Fz, and FCz, as shown in Figure 41 (Luck, 2014). Second, a more positive peak for old probes between 400 to 800 ms for old probes than for new probes with a maximal peak happening in the left parietal electrode sites, P3 and P7, as shown in Figure 41 (Luck, 2014). The first effect is sometimes called the "*midfrontal old-new effect* or *FN400* because it is like a frontally distributed N400," while the second effect is called the *left-parietal old-new effect* (Luck, 2014, p. 106).

While Curran (2000) and Rugg and Curran (2007) proposed that the *midfrontal old-new effect* is "associated with *familiarity* which is the more diffuse feeling that the probe has been encountered before," Paller, Voss, and Boehm (2007) and Voss, Lucas, and Paller (2012) proposed that the effect "reflects a boost in *conceptual fluency* which is the ease with which meaning is processed which is [a] precursor to familiarity" (Luck, 2014, p. 106). On the other hand, the *left-parietal old-new effect* has been associated with what the "memory researchers call *recollection* which refers to a clear and distinct experience of the memory that is linked with a particular time and/or a place" (Luck, 2014, p. 106). Table 4 presents a summary of the ERP components/paradigms that will be considered in this chapter.

Table 4: Summary of the ERP components/paradigms of interest.

ERP Component/ Paradigm	Time from Onset of Stimulus	Maximal Electrode Sites	Associated With
P3	300 ms	Pz	unfamiliarity with the stimulus
(memory) old-new probe paradigm	300 to 500 ms (more negative for new probes compared to old ones)	midline frontal (AFz, Fz, and FCz as shown in Figure 41)	familiarity with the probe (the diffuse feeling the probe has been encountered in the past) or boost in conceptual fluency
(memory) old-new probe paradigm	400 to 800 ms (more negative for old probes compared to new ones)	left parietal (P3 and P7 as shown in Figure 41)	recollection (a clear and distinct experience of the memory linked with a particular time and/or a place)

5.1.5 Crowdvoting

Crowdvoting is a form of crowdsourcing[43] where enough diverse number of people are asked to vote on a set of ideas, solutions, projects, actions, etc. (Becker et al., 2017). The aggregated vote obtained from the crowds can exceed the accuracy of the vote coming from few experts (e.g., Becker et al., 2017; Herzog & Hertwig, 2011; Kelley & Tetlock, 2013; Sunstein, 2006; Surowiecki, 2005). Crowdvoting has been used in different places, from predicting markets (Wolfers & Zitzewitz, 2004) and financial forecasting (Kelley & Tetlock, 2013; Nofer, 2015) to evaluating the creativity of design ideas (Bogdanović, Despotović-Zrakić, Naumović, Živojinović, & Bjelica, 2019). Crowdvoting will be used in this chapter to evaluate the ideas collected from the participants based on a set of creativity-related dimensions, as will be discussed later.

[43] Crowdsourcing is based on *The Wisdom of Crowds* principle discovered by Francis Galton in 1906 (Becker, Brackbill, & Centola, 2017). The principle states that not all crowd behavior is negative; indeed, if enough number of non-experts are asked the same question, the collective answer obtained from them might be better than the answer obtained from few experts (e.g., Becker et al., 2017; Surowiecki, 2005).

5.1.6 Engineers' Thinking Process

Due to the nature of the curriculum that engineering students go through, their way of thinking seems different from other students. In a linguistics experiment conducted by Jonczyk et al. (2019) where sentences with three types of meanings, namely, literal, metaphorical, and nonsensical ones (example sentences are shown in Table 5) were used, engineering students were found to mentally process the literal and metaphorical sentences in a way that is significantly different from the way they processed nonsensical ones. On the other hand, the non-engineering students were found to mentally process the metaphorical and nonsensical sentences in a way that is significantly different from the way they processed the literal sentences. This indicates that the results found in the general literature about creativity may not directly be applied to engineering.

Table 5: Example of the different types of sentences used in Jonczyk, van Hell, Kremer, and Siddique (2019) to study how engineers mentally process different types of sentences compared to non-engineers.

Meaning Type	Generic Example Sentence	Engineering-Related Example Sentence
Literal	The coffee you drank was warm.	The wind moved the turbine.
Metaphorical	The anger he felt was warm.	The wind tickled the turbine.
Nonsensical	The answer they gave was warm.	The wind ate the turbine.

5.2 Research Questions

This chapter seeks to answer RQ4: How is creativity different in engineering? by answering the following sub-research questions:

- RQ4.1: What is the relationship between (a) personal characteristics: biological factors, knowledge and experience, personality, creative self-efficacy, and creative potential; (b) task engagement; and (c) creative performance?
- RQ4.2: How do semantic cues affect creative performance?
- RQ4.3: How do semantic cues affect brain behavior?

Answering RQ4.1: What is the relationship between (a) personal characteristics: biological factors, knowledge and experience, personality, creative self-efficacy, and creative potential; (b) task engagement; and (c) creative performance? will be accomplished via correlational research. In contrast, RQ4.2: How do semantic cues affect creative performance? and RQ4.3: How do semantic cues affect brain behavior? will be answered via inferential statistics and linear regression methods based on a designed lab experiment with one factor (cue type) the consists of three levels: control, near semantic cue, and far semantic cue. The hypotheses associated with RQ4.2: How do semantic cues affect creative performance? and RQ4.3: How do semantic cues affect brain behavior? will be evaluated for any significant differences are listed in Table 6 and Table 7, respectively.

To validate the hypotheses associated with RQ4.2: How do semantic cues affect creative performance? and RQ4.3: How do semantic cues affect brain behavior?, an experiment detailed in Section 5.3.3 will be conducted. The first two hypotheses of RQ4.2: How do semantic cues affect creative performance? and the five hypotheses of RQ4.3: How do semantic cues affect brain behavior? will be evaluated for statistical significance using either the parametric ANOVA test if the data is normally distributed or the non-parametric Kruskal-Wallis test if the data is not normally distributed. Testing hypothesis 4-6 of RQ4.2: How do semantic cues affect creative performance? will first involve fitting a linear model to the data and then testing if the beta coefficients associated with the different cue types are statistically significant. Gathering multiple observations from the same participants, as what will be done in the experiment in this chapter, make the data coming from the same participant dependent. Hence, an advanced statistical technique such as hierarchical linear modeling (HLM) needs to be used to strip out the variance introduced by the individual participants when testing if treatment has any statistical effect.

Table 6: The list of hypotheses associated with RQ4.2: How do semantic cues affect creative performance? The experiment that will be used to answer these research questions has one factor (cue type) with 3 conditions: a=control, b=far, and c=near. The linear model for hypotheses 3-6 is $y_{ij} = \beta_a + \beta_b B_j + \beta_c C_j + \gamma_{0i} + \gamma_{1i} P_i + e_{ij}$, where β_a, β_b, and β_c represent the coefficient of the fixed effect and γ_{0i} and γ_{1i} represent the intercept and slope, respectively, of the random effect.

	Formal Hypothesis	**Statistical Hypothesis**	**Intended Statistical Test**
	Type of cue will affect …		
1	number of generated valid responses by participants	$H_{\emptyset}^{1\text{-}1}$: $\mu_a=\mu_b=\mu_c$ $H_{A}^{1\text{-}1}$: not $H_{\emptyset}^{1\text{-}1}$	one-way ANOVA or Kruskal-Wallis Test
2	creativity score of participants on the given task	$H_{\emptyset}^{1\text{-}2}$: $\mu_a=\mu_b=\mu_c$ $H_{A}^{1\text{-}2}$: not $H_{\emptyset}^{1\text{-}2}$	one-way ANOVA or Kruskal-Wallis Test
3	ideation duration of responses	$H_{\emptyset}^{1\text{-}3}$: $\beta_b=\beta_c=0$ $H_{A}^{1\text{-}3}$: not $H_{\emptyset}^{1\text{-}3}$	Hierarchical Linear Model (HLM)
4	appropriateness of generated valid responses	$H_{\emptyset}^{1\text{-}4}$: $\beta_b=\beta_c=0$ $H_{A}^{1\text{-}4}$: not $H_{\emptyset}^{1\text{-}4}$	Hierarchical Linear Model (HLM)
5	novelty of generated valid responses	$H_{\emptyset}^{1\text{-}5}$: $\beta_b=\beta_c=0$ $H_{A}^{1\text{-}5}$: not $H_{\emptyset}^{1\text{-}5}$	Hierarchical Linear Model (HLM)
6	creativity of the generated valid responses	$H_{\emptyset}^{1\text{-}6}$: $\beta_b=\beta_c=0$ $H_{A}^{1\text{-}6}$: not $H_{\emptyset}^{1\text{-}6}$	Hierarchical Linear Model (HLM)

Table 7: The list of hypotheses associated with RQ4.3: How do semantic cues affect brain behavior?. The experiment that will be used to answer these research questions has one factor (cue type) with 3 conditions: a=control, b=far, and c=near.

	Formal Hypothesis	**Statistical Hypothesis**	**Intended Statistical Test**
1	Familiarity with distinct types of cues will be different as shown by the amplitude of the P3 component when measured on the Pz site	$H_{\emptyset}^{2\text{-}1}$: $\mu_a=\mu_b=\mu_c$ $H_{A}^{2\text{-}1}$: not $H_{\emptyset}^{2\text{-}1}$	one-way ANOVA or Kruskal-Wallis Test
2	Recognizing distinct types of cues as uses for objects will be different as measured by the amplitude of the midfrontal old-new component of the old-new probe paradigm when measured on the **Fz** site	$H_{\emptyset}^{2\text{-}2}$: $\mu_a=\mu_b=\mu_c$ $H_{A}^{2\text{-}2}$: not $H_{\emptyset}^{2\text{-}2}$	one-way ANOVA or Kruskal-Wallis Test
3	same as (2) ... **AFz** ...	$H_{\emptyset}^{2\text{-}3}$: $\mu_a=\mu_b=\mu_c$ $H_{A}^{2\text{-}3}$: not $H_{\emptyset}^{2\text{-}3}$	one-way ANOVA or Kruskal-Wallis Test
4	Effort to utilize distinct types of cues to produce uses for the given objects will be different as shown by the left-parietal old-new component when measured on the **P3** site	$H_{\emptyset}^{2\text{-}4}$: $\mu_a=\mu_b=\mu_c$ $H_{A}^{2\text{-}4}$: not $H_{\emptyset}^{2\text{-}4}$	one-way ANOVA or Kruskal-Wallis Test
5	same as (4) ... **P7** ...	$H_{\emptyset}^{2\text{-}5}$: $\mu_a=\mu_b=\mu_c$ $H_{A}^{2\text{-}5}$: not $H_{\emptyset}^{2\text{-}5}$	one-way ANOVA or Kruskal-Wallis Test

5.3 Materials, Apparatus, and Tools

This section describes the different materials, apparatus, and tools used in the study as measures for the factors and activities mentioned in Section 5.1. This section will follow the same organization used in Section 5.1; it will start by describing the materials used to measure the personal characteristics (Section 5.3.1), followed by the materials used to measure the environmental factors (Section 5.3.2). It then moves to describe the materials used to measure the creative performance (Section 5.3.3) and ends up with a description of the apparatus that will be used to measure the cortical activity (Section 5.3.4). The exact structure will be maintained throughout this chapter to make it easy for the reader to move from the factors that will be considered in the study, the *what* part (Section 5.1); to the techniques used to measure these factors, the *how* part (this section, Section 5.3); to the procedures used to quantify the obtained results, the *technical how* part (Section 5.5); to the values obtained through the quantification process, the *results* part (Section 5.6). A visual summary of the varied factors used in the study with the proposed measures for each is shown in Figure 39.

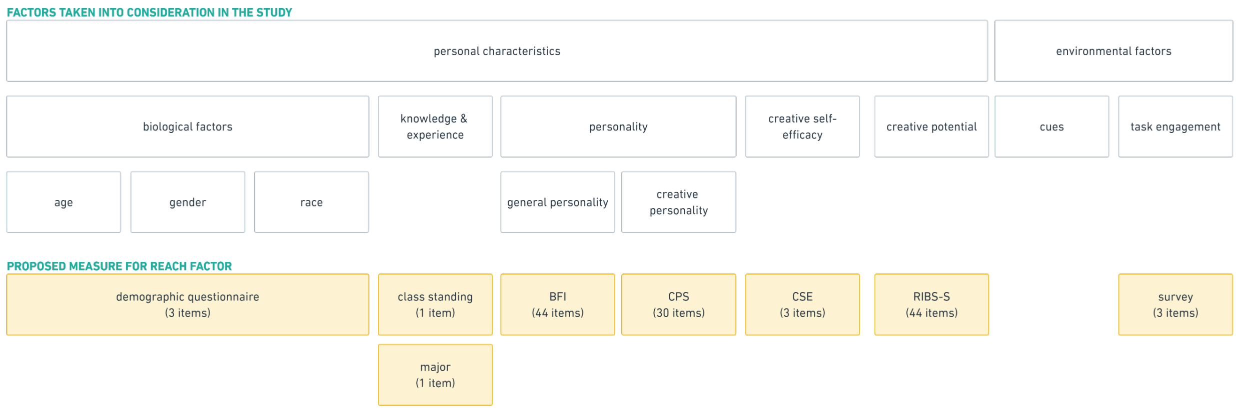

Figure 39: A visual summary of the various factors that will be considered in the study described in this chapter along with the corresponding measures for each factor.

5.3.1 Personal Characteristics

Except for the biological factors, various measures can be used to measure each of the personal characteristics introduced in Section 5.1.1. This section will explain the reasons behind selecting each of the measures for each of the selected factors. In general, the decision was based on one of more of the following criteria: (a) the validity of the measure as reported in the literature, (b) the time required to administer the measure, and/or (c) the effort required to quantify the responses obtained through the measure. Given the situations under which the study was conducted, i.e., the limited social interaction imposed by the COVID-19 pandemic, it was necessary to keep the experiment as short as possible without compromising its validity. Hence, the presence of the participants in the face-to-face setting was limited to the collection of the cortical activity. All the other required measures were posted online for the participants to fill in their own time. The total length of the online measures was also taken into consideration to avoid any rush when responding. These constraints impose another layer of restrictions on deciding which measure to select.

Biological Factors. Three personal characteristics related to the individual's biology will be considered in this study: age, gender, and race. In general, these researchers, as well lay people, would like to see how these factors related to the findings of any study. Hence, their relationship with the creative act considered for investigation in this study will be highlighted. The participants will be asked to indicate their age, gender, and race using the Demographic Questionnaire shown in Appendix I.

Knowledge and Experience. The knowledge and experience factor will be indirectly measured via (a) the class standing level, i.e., freshmen, sophomore, junior, senior, master's, or doctorate, and (b) the major of study. The participants will be asked to indicate their class standing and their major as part of the Demographic Questionnaire shown in Appendix I.

Personality. When measuring the personality of an individual, tails or characteristics are typically used (Abdullah et al., 2016; Allport, 1937; Weiner & Greene, 2017). Many models and theories, such as the ones by "Gordon Allport, Raymond Cattell, Hans Eysenck, Katherine Brigg, and Isabel Brigg" have been proposed to uncover the personality traits of an individual (Abdullah et al., 2016, p. 178). Among these theories, the *Big Five Model*[44] is the one that received a general agreement from psychologists due to its validity and stability (Abdullah et al., 2016; Conley, 1985; Costa & McCrae, 1988; Goldberg, 1981; McCrae, 1989, 2017; McCrae & Costa, 1985, 1987; Wortman, Lucas, & Donnellan, 2012). Therefore, the Big Five Model is the one that will be adopted as a measure for personality in the study reported in this chapter.

The Big Five Model consists of 5 generic/essential personality traits: *neuroticism*[45], *extraversion*[46], *openness to experience*[47], *agreeableness-antagonism*, and

[44] "The term 'Big Five' was coined by Lew Goldberg and was originally associated with studies of personality traits used in natural language" (Srivastava, 2021).

[45] The neuroticism trait is sometimes reversed and called *emotional stability* (Abdullah et al., 2016; Srivastava, 2021).

[46] The extraversion trait is sometimes called *surgency* (Abdullah et al., 2016; Srivastava, 2021).

[47] The openness to experience trait is sometimes called *intellect* or *intellect/imagination* (Abdullah et al., 2016; Srivastava, 2021).

conscientiousness-undirectedness. The *neuroticism* trait represents the person's level of stability and is defined by adjectives such as worrying, insecure, self-conscious, and temperamental (Abdullah et al., 2016; John, Naumann, & Soto, 2008; McCrae & Costa, 1987). The *extraversion* trait represents the degree to which an individual is comfortable communicating and building a relationship with others and is associated with adjectives such as talkative, energetic, and assertive (Abdullah et al., 2016; Barrick & Mount, 1991; Hermes, Hagemann, Naumann, & Walter, 2011; John et al., 2008; McCrae & Costa, 1987). The *openness to experience* trait represents one's imagination and fascination level and is defined by adjectives such as curiosity, creativity, and sensitivity (Abdullah et al., 2016; John et al., 2008; McCrae & Costa, 1987). The *agreeableness-antagonism* trait represents the degree to which an individual agrees with others and is represented by adjectives such as sympathetic, kind, and affectionate (Abdullah et al., 2016; John et al., 2008; McCrae & Costa, 1987). The last trait, *conscientiousness-undirectedness*, represents the individual's level of reliability and is defined by adjectives such as organized, thorough, and planful (Abdullah et al., 2016; John et al., 2008; McCrae & Costa, 1987).

There are a variety of ways to measure the traits proposed by the Big Five Model. One of them is the International Personality Item Pool (IPIP) proposed by Goldberg, Johnson, Eber, Hogan, Ashton, Cloninger, and Gough (2006) and the Big Five Aspect

Scales (BFAS) proposed by DeYoung, Quilty, and Peterson (2007). The one that will be used in this study is the Big Five Inventory (BFI) proposed by John et al. (2008) due to its moderate length—it consists of 44 items compared to IPIP, which consists of 3,320 items, and BFAS, which consists of 100 items. The participants are asked to indicate their agreement with 44 statements on a scale from 1 (strongly disagree) to 5 (strongly agree). Appendix II presents the survey in which the BFI is administered.

In addition to using Big Five Inventory to assess the general personality, the *Creative Personality Scale* (CPS, Gough, 1979) has been chosen to assess the creative personality. The scale consists of a list of 30 creativity-related adjectives, e.g., capable, egotistical, artificial, and cautious (see Appendix III for the complete list and for the survey in which the scale is administered), and individuals are asked to select the adjectives that best describe their creative personality. The list contains (a) 18 adjectives positively associated with creativity, e.g., capable, egotistical, and (b) 12 adjectives negatively associated with creativity, e.g., artificial and cautious. CPS is a valid and reliable scale—the reliability of the scale has been reported in the literature to be between .73 and .81 (An & Runco, 2016). CPS has also been shown to have a strong correlation with creativity measures such as Domino's Scale for Creativity, Schaefer's Scale for Creativity, and Welsh's Four Creativity Scales (An & Runco, 2016; Gough, 1979).

Creative Self-Efficacy. The scale proposed by Tierney and Farmer (2002), the *Creative Self-Efficacy* (CSE) scale, is the one that will be adopted in this study. CSE is one of the most frequently used scales to measure creative self-efficacy (M. Tang et al., 2017) and has a reliability level between .83 and .87 (Tierney & Farmer, 2002). The scale consists of 3 items/statements, e.g., "I am good at coming up with new ideas." The participants are asked to indicate their agreement with these statements on an ordinal scale that ranges from 1 (strongly disagree) to 5 (strongly agree)[48]—the full list of items is available in Appendix IV which includes the survey in which the scale is used.

Creative Potential. The creative potential will be measured through the ideation behavior via the short form of the *Runco Ideation Behavior Scale*[49] (RIBS-S, Runco, Plucker, & Lim, 2000). RIBS has a reliability score between .90 and .92 (Runco, 2010; Runco et al., 2000). RIBS-S consists of 18 items that ask the individuals about their thinking behavior through phrases such as "I have ideas for arranging or rearranging the furniture at home" and "I have ideas for making my work easier." The scale focuses

[48] The original "scale was rated on a seven-point format (1, "very strongly disagree"; 7, "very strongly agree") (Tierney & Farmer, 2002, p. 1142).

[49] RIBS-S is part of Runco Creativity Assessment Battery (rCAB).

on the thinking behavior and not the actual behavior. The participants are asked about the frequency of their ideation behavior about each of the presented items on an ordinal scale that ranges from 0 (never) to 4 (just about every day, and sometimes more than once every day). The full scale as delivered to the participants is shown in Appendix V.

5.3.2 Environmental Factors

Cues. Two types of cues, namely, near and far cues, related to the task outlined in Section 5.3.3 below, will be investigated for their effect on creative performance. The cues and their associated objects were adopted from a study by Hartog, Marshall, Ahad, Alhashim, Kremer, van Hell, and Siddique (2020). The complete list after modification is available in Appendix VI.

Task Engagement. A three-item survey will be used to measure the level of engagement the participants went through when performing the given task. The survey was inspired by the *Immersive Experience Questionnaire* (IEQ) developed by Jennett, Cox, Cairns, Dhoparee, Epps, Tijs, and Walton (2008) and the *Game Engagement Questionnaire* (GEQ) developed by Brockmyer, Fox, Curtiss, McBroom, Burkhart, and Pidruzny (2009). IEQ and GEO are prominent examples of statistically validated questionnaires used in the gaming field to evaluate player experience (Nordin, Denisova, & Cairns, 2014). The survey used here, which was inspired by these two questionnaires, however, was not validated. The survey was meant to collect a high-level estimate of the participants' engagement with the given to correlate it with the performance on the given task.

The survey asks the participants to evaluate their experience with the task that they just finished, i.e., the creative task, by answering 3 questions, e.g., "How engaging the experiment was to you?" on a bipolar scale that ranges from 1 (e.g., boring) to 5 (e.g., interesting). The complete survey as delivered to the participants is available in Appendix VII.

5.3.3 Creative Performance

To measure the creative performance of the participants, the *Alternative Uses Task*[50] (AUT) measure will be used. AUT is one of the widely used measures for creative performance (Gilhooly, Fioratou, Anthony, & Wynn, 2007; Olson, Nahas, Chmoulevitch, & Webb, 2020). AUT was proposed by Guilford (1950) and later included and made

[50] Other names and varieties found in the literature for the Alternative Uses Task are *Guilford's Alternative Uses Task*, *Guilford's Brick Uses Test*, *Torrance's Tin Can Uses Test*, *Cardboard Boxes Uses Test*, *Alternative Uses of Common Objects*, *Many Uses Game* (Runco, 2011b), *Unusual Uses of Common Object Test*, and *Novel Uses Task*.

Figure 40: Example pictures of the SMARTING mobi system by MBrainTrain used to collect EEG data in the experiment. The pictures were borrowed from mbraintrain.com/smarting-mobi

famous through the *Torrance Test of Creative Thinking* (TTCT) proposed by Torrance (1966). AUT is a divergent thinking test where the test taker is asked to generate alternative uses for a set of day-to-day objects, usually under a given time limit. The objects for which the participants will be asked to generate alternative uses were adopted from Hartog et al. (2020) and is available in Appendix VI.

5.3.4 Cortical Activity

Recording EEG. To record the cortical activity of the participants, the wireless mobile EEG system by MBrainTrain, SMARTING mobi[51] (Figure 40), will be used. The system consists of (a) a Bluetooth-operated amplifier, the white device attached to the EEG cap shown in Figure 40, (b) a USB Bluetooth dongle responsible for making the communication between the amplifier and the machine on which the experiment is being delivered, and (c) a software system responsible for collecting and managing the data sent by the amplifier and possibly other software systems. The system was used with a 24-electrode EasyCap EEG cap (the black fabric piece shown in Figure 40 into which 24 electrodes are attached). The EEG cap is preconfigured based on the international 10-20 system introduced in Section 5.1.4. See Figure 41 for the mapping of the 24-electrode in the EasyCap EEG cap to the 10-20 system.

To ensure high-quality EEG signals, a conductive get needs to be applied underneath the 24 electrodes after fitting the EEG cap on the participant's head. The impedance level of the electrodes needs to be kept low, i.e., below 10 kΩ.

[51] Website is mbraintrain.com/smarting-mobi

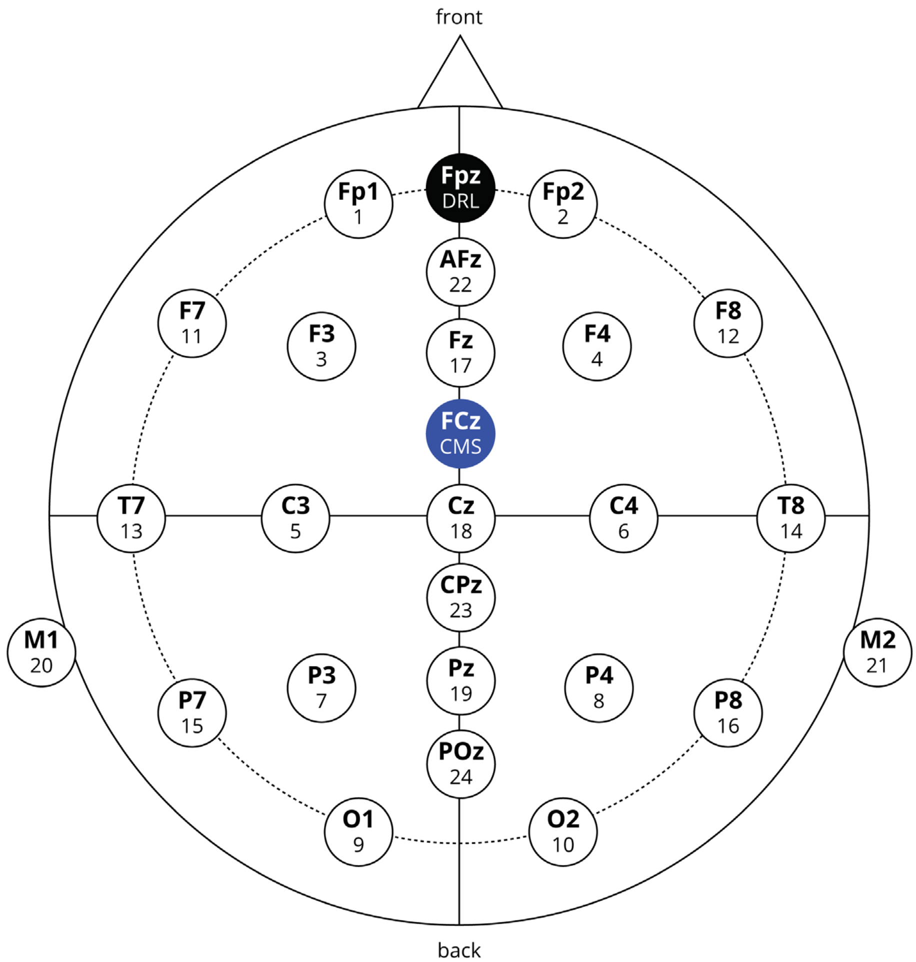

Figure 41: The layout of electrodes of the EasyCap EEG cap used with MBrainTrain SMARTING mobi EEG system shown in Figure 40. The circles represent the electrodes' locations placed according to the 10-20 system. The first line of text inside the circles reflects the label of the electrode site as given by the 10-20 system while the second line reflects the name/label used by the SMARTING software system.

EEG to ERP. Eliciting the ERPs from the collected EEG data will be performed using two MATLAB graphical user interface (GUI) environments: EEGLab and ERPLab.

These GUI environments are maintained by the Swartz Center for Computational Neuroscience, Institute for Neural Computation, University of California San Diego[52]. The procedure outline in Section 5.1.4 will be followed to elicit the ERPs using the functionalities provided by the EEGLab and ERPLab GUI environments.

5.3.5 Stimuli Delivery

The stimuli involved in the study, i.e., the cues described in Section 5.3.2 and the objects used in the creative task described in Section 5.3.3, will be delivered using the Presentation software[53] developed by Neurobehavioral Systems, Inc.[54]. The study will be coded using the Scenario Description Language (SDL) and the interpreted programming language Presentation Control Language (PCL). SDL is used to describe the stimuli and their sequence in the scenario, while PCL is used to implement a custom control of the required scenario. In other words, SDL is typically used to determine *what* to present in the scenario, while PCL is typically used to determine *how* to present the scenario.

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[52] sccn.ucsd.edu

[53] version 22.1 build 01.21.21

[54] neurobs.com

5.3.6 Data Analysis

The data analysis will be performed using the statistical computing language and environment, R, via the integrated development environment, RStudio[55]. EEGLab and ERPLab introduced in Section 5.3.4 will be used to analyze the EEG data.

5.4 Methodology

This section details (a) the procedure followed when recruiting volunteers to participate in the study (Section 5.4.1) and (b) the experiment design and procedure that were followed when the study was conducted (Section 5.4.3).

5.4.1 Participants

After approving the study by the Institutional Review Board (IRB) office of the University of Oklahoma, colleagues from the Gallogly College of Engineering, the University of Oklahoma, have been approached to inquiry about their interest in participating in the study. A total of seven participants had shown interest. The mean

[55] rstudio.com

Table 8: A summary of the demographic information of the participants (N=7). Race sums to more than 100% because the participants could select more than one race when describing themselves; other demographics such as class may not sum to 100% because of the rounding.

Race	
Hispanic, Latino, or Spanish Origin	14%
White	29%
Middle Eastern or North African	71%
Gender	
Female	29%
Male	71%
Class	
Senior	29%
Masters	29%
Doctoral	43%
Major	
Environmental Engineering	14%
Geology	14%
Mechanical Engineering	14%
Civil Engineering	14%
Chemical Engineering	14%
Industrial & Systems Engineering	29%

age of the participants is 29.2±4.4 years old. Table 8 summarizes the demographic information of the participants.

5.4.2 Experiment Setup

After showing interest in the study, the participants were invited to schedule a time to come to the lab to do the EEG portion of the study. Upon arrival to the lab, the participants were greeted and seated in front of a laptop used for the study. The circumference of the participants' heads was then measured to determine the right-fit size of the EEG cap. The participants were then asked to put the appropriate EEG cap on while ensuring that the midline center electrode is falling in the middle between the nasion and the inion (see the top-left illustration in Figure 38 for an illustration). After fitting the EEG cap, the steps mentioned in Section 5.3.4, i.e., applying a conductive get and keeping the impedance level to a low level, were performed. By the end of these steps, the experiment's setup was considered complete, and the participants were ready to complete the task.

5.4.3 Experiment Design & Procedure

The experiment followed the within-subject design paradigm, where all the participants were exposed to all the treatments. The experiment consisted of two parts: (a) a part done in the lab where the cortical activities were recorded and (b) another done outside the lab on the participant's own time. The part done in the lab consists of two portions: (a-1) the Alternative Uses Task (AUT) portion introduced in Section 5.3.3 followed by (a-2) the task evaluation survey portion mentioned in Section 5.3.2. The stimulus delivery mechanism mentioned in Section 5.3.5 was used to administer the AUT—the names of the objects were flashed on the screen for the participants. The participants were instructed to think of an alternative use for each of the flashed objects.

Before flashing the objects, an associated cue that either represents a near-use example of the object that will be shown or a far-use example had first been shown. These two types of cues represent the two treatment groups besides the control group, where no cue was shown before flashing the object. When no cue is shown, a '?' mark was shown instead. After shown the cue and the object, the participants were instructed to think of a novel, useful use of the object as quickly as possible. When done thinking, the participants were asked to click 'enter' where a new screen promoting the idea was shown. After typing the idea, the same process repeats. Twenty-five objects chosen at random from the 56 objects shown in Appendix VI were delivered to the participants.

Each object appeared three times, two times proceeded by a cue, and a third time proceeded with a '?' mark, i.e., no-cue. Like the objects, the order of the cues was randomized, i.e., the near-cue could appear before or after the far-cue and before or after the no-cue. In total, the participants went through 75 trials. At the beginning of each trial, a '+" sign was shown, and the participants were instructed to utilize this time to free their minds from any distraction. After showing the cue and before showing the object, a blank screen lasting 500 ms were presented. A portion of the period of the '+' sign screen and the blank screen will be used as a baseline when calculating the ERPs as described in Section 5.1.4.

After finishing the Alternative Uses Task (AUT), the participants were asked to evaluate their engagement with the task using the survey presented in Section 5.3.2. The survey was shown directly after finishing the AUT. After filling the task evaluation survey, the participants were thanked for their participation in the study and asked to remove the EEG cap. After that, the participants were handed a piece of paper with a website link pointing to the second part of the experiment, i.e., the survey. The paper also included a random identification number assigned to the participants upon agreeing to participate in the study. The participants were asked to enter this number when filling the survey to match the two parts of the experiments. The survey consists of five parts: (a) the demographic questionnaire presented in Section 5.3.1, (b-e) the Big Five Inventory survey, the Creative Personality Scale survey, the Creative Self-Efficacy survey, and the Runco Ideation Behavior Scale survey introduced in Section 5.3.2.

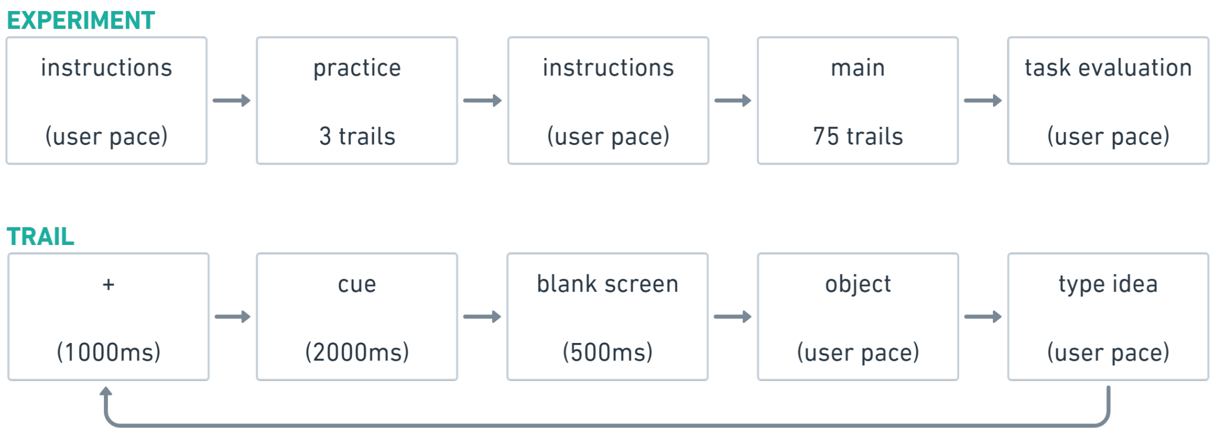

Figure 42: The order in which the instructions and the stimuli are shown to the participants. Each box represents either an instruction or a stimulus. The text between parentheses at the bottom of the boxes shows the duration of the instruction/stimulus when shown to the participant on the screen. If the value says 'user pace' then the instruction/stimulus is shown till the user perform the promoted action, e.g., hitting enter.

5.5 Quantification Procedures

This section detailed the process that was followed to turn the responses obtained from the participants during the experiment into quantities suitable for analysis. The process includes (a) coding categorical factors, (b) cleaning raw data, and (c) evaluating responses on a set of creativity-related dimensions. After applying the procedures detailed in this section, the collected data should be ready for the analysis explained in Section 5.6.

Table 9: The corresponding nominal values for each answer to the gender question.

Gender	Corresponding Nominal Value
Female	0
Male	1
Non-binary / third gender	2
Prefer not to answer	NA

5.5.1 Personal Characteristics

Biological Factors. The answers to the age question will be used as entered, i.e., ordinal data. On the other hand, the answers to the gender question will be coded as nominal values, as shown in Table 9. Since the participants can select more than one race when describing themselves, each race option will be treated as a separate binary variable. A value of '1' in the corresponding race variable indicates that the race was selected, while a value of '0' indicates otherwise. Table 10 lists the abbreviated names that will be linked with each race option.

Table 10: The list of abbreviated names that will be associated with each race option.

Race	**Abbreviated Name**
Hispanic, Latino, or Spanish Origin	Hispanic
White	White
Middle Eastern or North African	MEast
Asian	Asian
Black	Black
North American Indigenous	NAIndi
Pacific Islander	PIslander
Prefer not to say	NA

Knowledge and Experience. The answers to the knowledge and experience questions used in the Demographic Questionnaire (Appendix I) will be turned into ordinal values, as shown in Table 11. This means that the score for the knowledge and experience can range from 0 (low knowledge and experience) to 4 (high knowledge and experience). During this study, only the class standing will be used as a proxy to knowledge and experience; the major will only be used to explain the differences in performance if any.

Table 11: The corresponding ordinal values for each answer to the class standing question.

Class Standing	Corresponding Ordinal Value
Freshman	0
Sophomore	1
Junior	2
Senior	3
Masters	4
Doctorate	5

Personality. To calculate the *personality score* obtained through the Big Five Inventory, the associated key proposed by John et al. (2008) will be used (see Appendix II for a copy of the key). The average score for each trait of the Big Five Model will be calculated separately[56]. The scores are then shifted by -1. This means that the score for any trait will range from 0 (low probability that the individual possesses the trait) to 4 (high probability that individual possesses the trait).

To calculate the *creative personality score* based on the answers provided on the Creative Personality Scale (CPS, see Appendix IVIII for the used survey), participants

[56] See John et al. (2008) for a more sophisticated scoring scheme where the individuals' acquiescent response style was taken into consideration.

receive +1 point for each selected positive adjective associated with creativity and -1 for each selected negative adjective. This means that the total score that a participant can receive on this scale can range from -12 (highly non-creative personality) and 18 (highly creative personality).

Creative Self-Efficacy. To calculate the participants' *creative self-efficacy score*, their answers on the Creative Self-efficacy (CSE) survey (Appendix IV) are averaged. The scores are then shifted by -1 to make it consistent with the scale range of the other measures. Hence, the participants' creative self-efficacy scores can range from 0 (low creative self-efficacy) to 4 (high creative self-efficacy).

Creative Potential. To calculate the participants' creative potential, their answers on the Ideation Behavior (IB) survey (Appendix V) are averaged. Hence, a participant can receive a score that ranges from 0 (low creative potential) to 4 (high creative potential).

5.5.2 Environmental Factors

Cues. The common and creative use examples used for the objects presented in the experiment performed by Hartog et al. (2020) were used as cues in this study. Common examples were used as near cues, while creative use examples were used as far cues.

Appendix VI lists all the objects used in the study with their corresponding near and far cues.

Task Engagement. The engagement of the participants with the given task was calculated based on the average score to the answers provided on the task engagement survey (Appendix VII). The scores are then shifted by -1 to make them consistent with the scales by the other measures. Hence, the task engagement score can range from 0 (low engagement) to 4 (high engagement).

5.5.3 Creative Performance

Before evaluating the creativity of the responses given to the task introduced in Section 5.3.3, the space-filling responses that have no meaning, such as "idk[57]" and "none," were first removed. Any response that includes the shown cue or the promoted object was also excluded from the evaluation. Responses that do not represent uses of the promoted objects were also excluded. The remaining responses were then be judged on two

[57] idk and IDK stand for "I don't know."

commonly agreed-up dimensions for creativity: novelty[58] and appropriateness[59] (Runco & Jaeger, 2012).

The novelty and the usefulness of the given responses, i.e., the uses given by the participants for the promoted objects, were judged by the crowds via Amazon Mechanical Turk service (mTurk, mturk.com). The workers on the service were asked to evaluate the novelty of the uses given to the objects on an ordinal scale that range from 1 (I almost always encounter this use for the object) to 5 (I never encounter this use for the object). The workers were also be asked to evaluate the appropriateness of the uses given to the object on an ordinal scale that range from 1 (the use for the object is very inappropriate) to 5 (the use for the object is very appropriate).

Before computing the average novelty and appropriateness score for each response based on the ratings received from the raters, inter-rater reliability was calculated. Any rater that has a low correlation value with the rest of the raters was considered for

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[58] Novelty is often used in different contexts to mean *originality*, *uniqueness*, *unconventionality*, *uncommonness*, *unusualness*, or *unexpectedness* (Bayliss, 2016; Kim, 2011; Shah, Smith, & Vargas-Hernández, 2003; Urban, 2004).

[59] Appropriateness is often used in different contexts to mean *quality*, *effectiveness*, *relevance*, *usefulness*, *feasibility*, or *utility* (Bayliss, 2016; Kim, 2011; Shah et al., 2003; Urban, 2004).

elimination. The average novelty and appropriateness scores were then calculated based on the ratings given by the remaining raters. After that, -1 was subtracted from the average and divided by 4 to compute the creativity score, which is a multiplication of the novelty score and the appropriateness score. Hence, the measures of the creative dimensions (novelty and appropriateness) and the creativity score range from 0 (less novel use, less appropriate use, less creative use) to 1 (highly novel use, highly appropriate use, highly creative use).

Besides evaluating the novelty and the appropriateness of the given responses, the time taken to generate ideas (ideation duration) was considered when evaluating the creative performance.

5.5.4 Cortical Activity

All the steps outlined in Section 5.1.4 required to generate ERPs from the collected raw EEG signals were performed using two MATLAB GUI environments, EEGLab and ERPLab, introduced in Section 5.3.4. Besides generating the ERPs for each participant under each treatment condition, the grand average ERPs for all the participants were also computed. The focus will be on the electrode sites where the effect of the ERP components/paradigms of interest (see Section 5.3.4 for details) are maximal.

5.6 Data Analysis and Results

This section starts by reporting the results of the evaluation of the participants' creative performance using the crowdsourcing service. The section then reports the findings for each of the research questions posed in Section 5.2.

5.6.1 Evaluating Creative Performance

The total number of the (non-empty) responses collected from all the 7 participants was 421 responses out of an expected 525 responses if all the 7 participants gave a response in each of the 75 trials. Out of these responses, 3 responses were space-filling responses, e.g., responses such as "idk" and "none"; this brings the total to 418 responses. After that, 9 responses that repeated the given cue and/or the promoted object were excluded; this brings the total to 409 responses. Then, 36 responses that did not represent uses for the promoted objects were removed; this brings the total to 373 responses.

The remaining 373 responses were evaluated using the procedure outlined in Section 5.5.3. The set was divided into two smaller sets: a set of 248 responses and another of 125 responses[60]. Thirteen raters were recruited to evaluate the 1st set of responses, and 8 were recruited for the 2nd set. Before averaging the scores obtained from the raters, the correlation matrices between the raters were calculated for the two creativity evaluation criteria, as shown in Figure 43.

[60] The division of the responses into two sets was not intentionally but it turns out to be beneficial especially when considering the time needed to evaluate this extensive list of responses twice: once for each criterion.

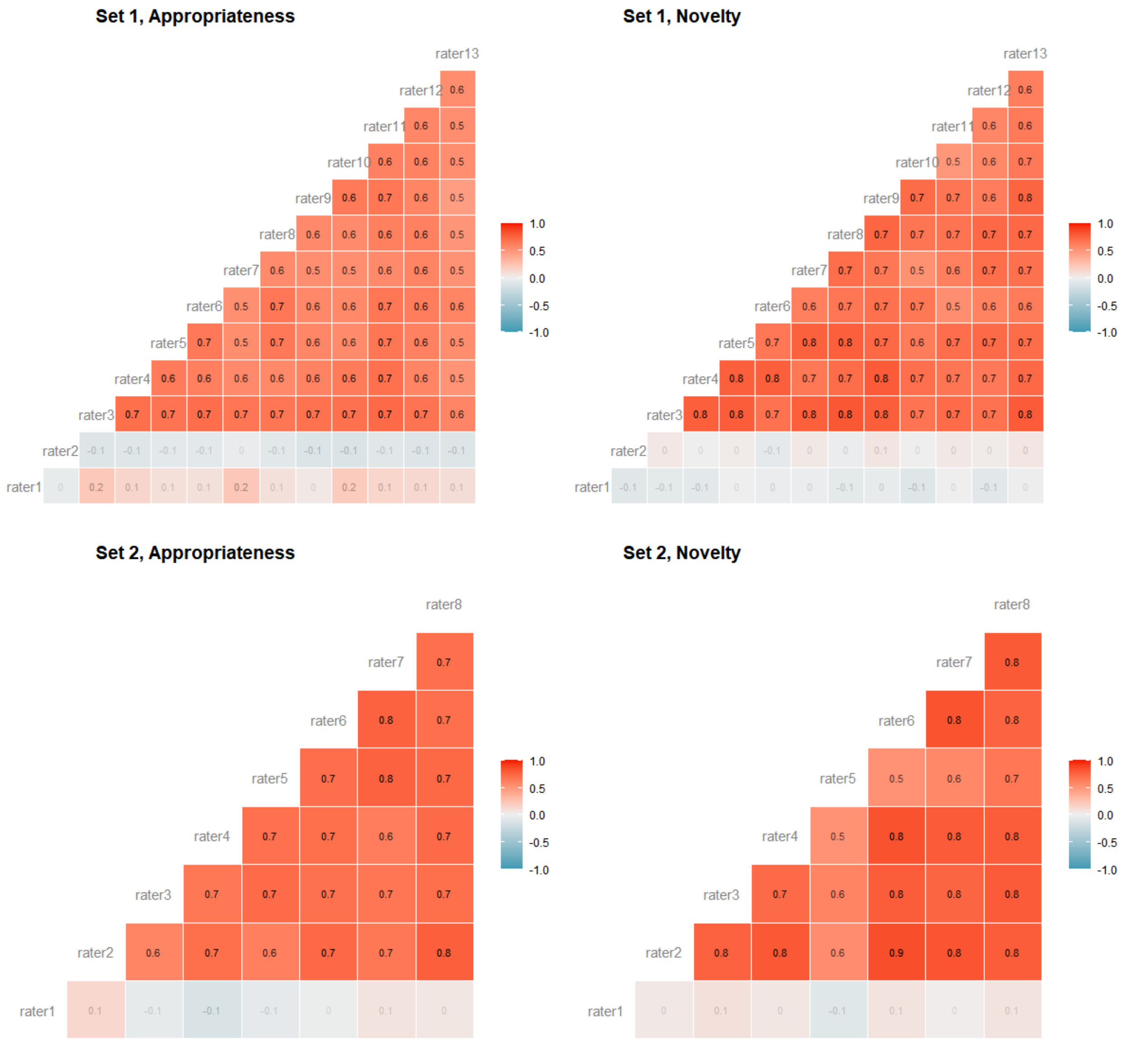

Figure 43: The correlation matrices between two sets of raters evaluating two sets of responses on two dimensions of creativity.

Since rater 1 and 2 in the 1st set and rater 1 in the 2nd set had low correlation values with the rest of the raters in their corresponding sets on both creativity evaluation criteria, their scores had been excluded when calculating the average scores. The *inter-rater reliability* (IRR) statistics[61] before and after excluding the raters mentioned above from their corresponding sets are shown in Table 12 for each creativity evaluation criterion. Since the scores are on an ordinal scale and more than two raters were randomly recruited to rate the whole set, the two-way mixed, consistency, average measures *intra-class correlation*[62] (ICC) statistics were used to assess the IRRs (Hallgren, 2012). Based on Cicchetti (1994)'s guidelines, the ICC statistics shown in Table 12 represent excellent IRR scores indicating that raters have a high degree of agreement and suggesting that the creativity evaluation criteria were rated similarly across raters. These high ICCs suggest that a minimal amount of measurement error was introduced by the independent raters, and therefore statistical power for subsequent analysis is not substantially reduced.

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[61] *Inter-rater reliability* is also known as *inter-rater agreement* and it measure the degree of consistency between multiple independent raters about certain features of a particular act (Hallgren, 2012).

[62] Unlike Cohen (1960)'s kappa, which is based on the all-or-nothing agreement, ICC statistics is based on the magnitude of disagreement—the higher the magnitude of the disagreement is, the lower the ICC statistics will be (Hallgren, 2012).

Table 12: The inter-rater reliability statistics based on the intra-class correlation (ICC) statistics for the two sets of scores obtained from two sets of raters for the two criteria of the creative performance.

	Before	**After**
Set 1 appropriateness	0.92 F(247,2964)=13, p=0	0.94 F(247,2470)=16.9, p=0
Set 1 novelty	0.94 F(247,2964)=16.9, p=0	0.96 F(247,2470)=25, p=0
Set 2 appropriateness	0.90 F(124,868)=10.1, p=0	0.93 F(124,744)=16.2, p=0
Set 2 novelty	0.91 F(124,868)=11.5, p=0	0.94 F(124,744)=19.8, p=0

Creativity evaluation criteria were therefore deemed to be suitable for use when answering

RQ2: What models of creativity exist?

5.6.2 RQ4.1: What is the relationship between (a) personal characteristics: biological factors, knowledge and experience, personality, creative self-efficacy, and creative potential; (b) task engagement; and (c) creative performance?

The results of the biological factors (age, race, and gender), and knowledge and experience mentioned in Section 5.4.1, are visually depicted in Figure 43. When appropriate, the figure also reports the coding scheme that was proposed in Section 5.5.1.

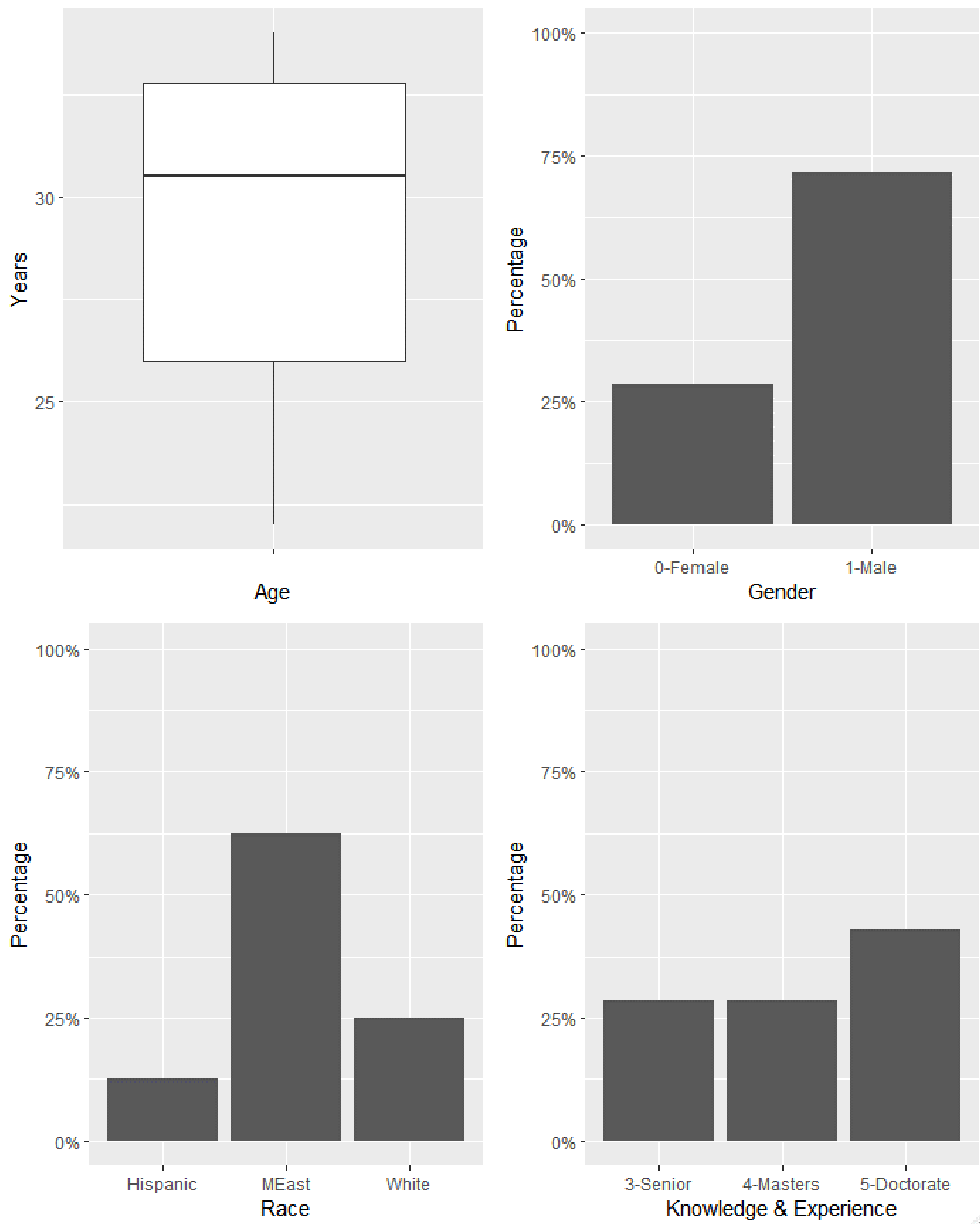

Figure 44: A visual depiction of the biological factors (age, race, and gender) and knowledge and experience factor reported by the participants.

The rest of the biological factors, namely, (a) general personality, (b) creative personality, (c) creative self-efficacy, and (d) creative potential, are summarized visually in Figure 45. Overall, the participants are close to average in all the *personality traits*—a median score of 2.7 out of 4 for the agreeableness trait, 2.2 out of 4 for the conscientiousness trait, 2.3 out of 4 for the extraversion trait, 1.4 out of 4 for the neuroticism traits, and 1.9 out of 4 for the openness traits. In terms of the *creative personality*, the participants, overall, described themselves with one more adjective that is positively associated with creativity than the number of negative adjectives associated with creativity. In terms of *creative self-efficacy*, the participants, overall, have average beliefs that they can perform tasks in creative ways—the median score is 2 out of 4. In terms of the *creative potential*, the participants, overall, have a below-average latent potential for creativity—the median score is 1.4 out of 4. In terms of *task engagement*, the participants, overall, showed an average engagement with the creative task—the median score is 2 out of 4.

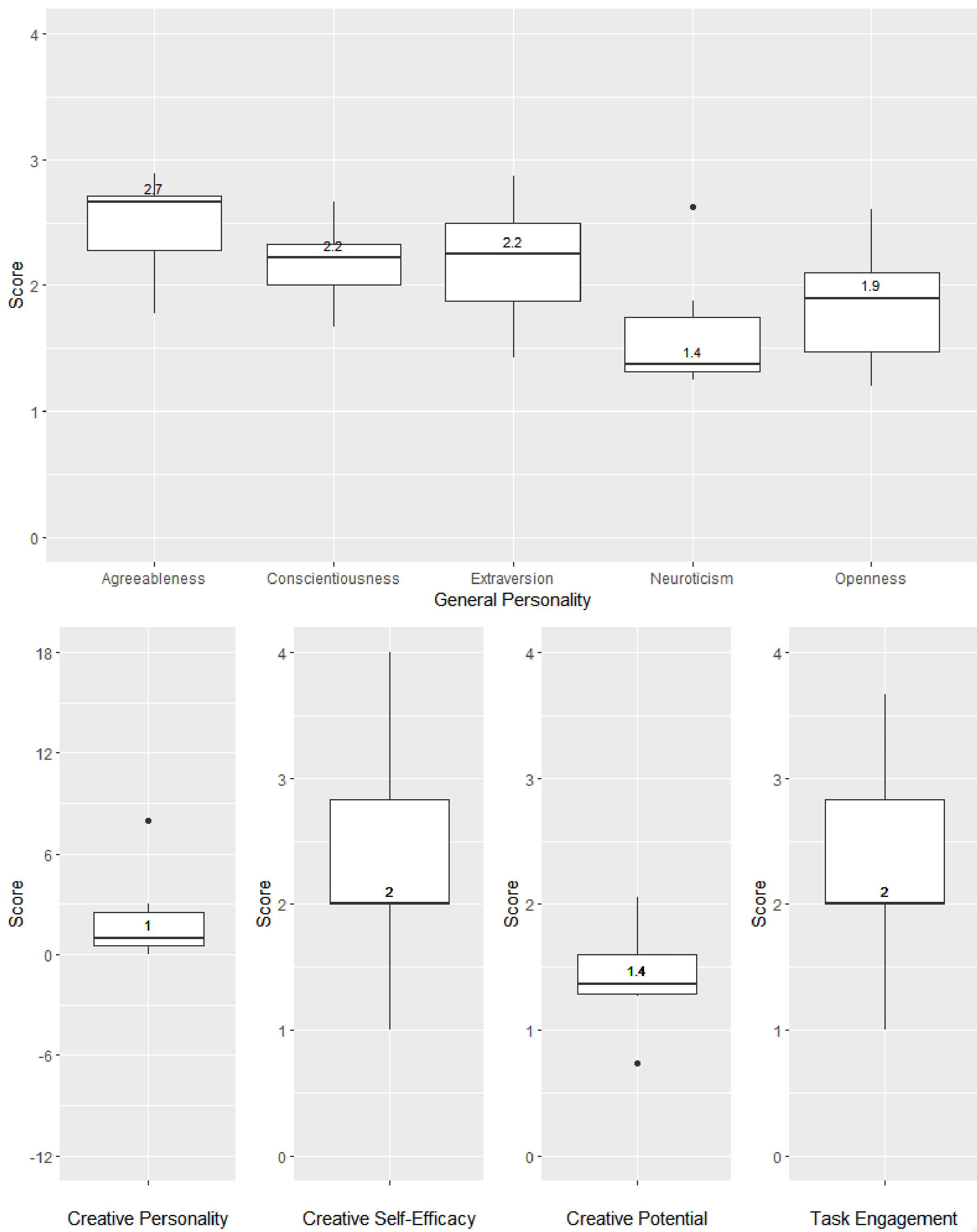

Figure 45: A visual depiction of four personal characteristics (general personality, creative personality, creative self-efficacy, and creative potential) and an environmental factor (task engagement) reported by the participants.

Figure 46 presents the five measures for the creative performance of the participants. The measures include (a) number of ideas, (b) average ideation duration, (c) average novelty score, (d) average appropriateness score, and (e) average creativity score. The measures had been calculated under 3 conditions: (i) considering all the responses, i.e., including empty and invalid ones; (ii) considering only the non-empty responses, i.e., excluding empty ones; and (iii) considering only valid responses, i.e., excluding empty and invalid responses as described in Section 5.5.3. In terms of the *number of generated responses*, the participants were expected to generate a median of 75 responses, but only a median of 50 valid responses was given. In terms of the *ideation duration*, the participants spend a median of 13.7 s trying to ideate a response, a median of 12.7 s ideating a response, and a median of 12 s ideating a valid response. This indicates that even if a longer time was spent trying to produce an idea, the participants either failed to produce a response or produced an invalid one.

Regarding the measures related to the *creativity of the produced responses*, the results were close when not considering the empty responses. The *novelty scores* increased from a median of 0.3 when considering all the ideas to a median of 0.7 when considering the non-empty and valid responses. The *appropriateness scores* slightly increased from a median of 0.4 when considering all the ideas to a median of 0.5 when considering the non-empty and valid responses. Following the same pattern, the *creativity scores* increased from a median of 0.1 when considering all the responses to a median of 0.3 when considering the non-empty and valid responses.

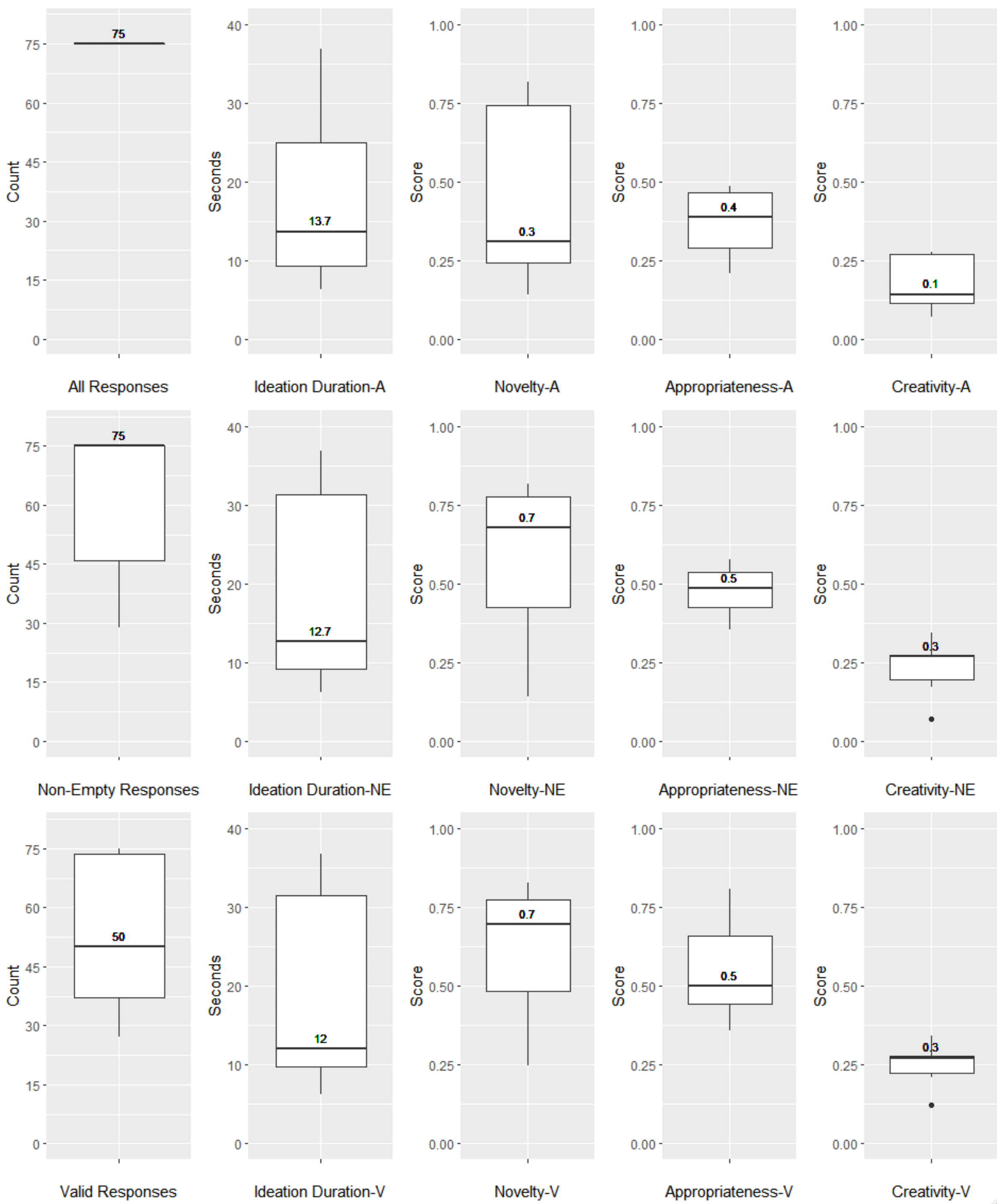

Figure 46: A visual depiction of the five measurements of the creative performance computed under three condition: all responses (top plots labeled with the suffix A), i.e., without excluding the empty and invalid ones; only non-empty (middle plots labeled with the suffix NE) responses, i.e., excluding the empty ideas but keeping the invalid ones; only valid responses (bottom plots labeled with the suffix V) ideas, i.e., excluding both the empty and invalid ones.

To understand the **strength of association** between the personal characteristics (age, gender, race, knowledge and experience, general personality, creative personality, creative self-efficacy, and creative potential), task engagement, and creative performance on the given task, Pearson's r correlation shown in Figure 47 was computed. The strength of the association is represented through the size of the circles—the larger the circle is, the stronger the association between the variables where the circle appears is. The direction of the association is represented through the color of the circle, where a blue color means a positive association and a red color means a negative association, and the darker the color is, the stronger the association between the intersecting variables is. The 'X' mark drawn on the top of the circles indicates that the association is not significant, i.e., $p>0.05$.

Regarding the *number of generated valid ideas*, the data suggests that it has a significant negative association with age and the *level of engagement* with the creative task. This means that younger participants tend to generate more valid ideas than their older counterparts. Also, the more the participants enjoyed the task, the smaller number of valid ideas they produced.

Regarding the *average time spent generating ideas*, the data suggests that it has a significant negative association with *knowledge and experience* and the *extraversion* personality traits. This means that the more knowledgeable and experienced the participants are, the less time they spent generating valid ideas. Also, the more extraversion the participants are, the less time they spent generating valid ideas.

Regarding the *appropriateness score*, the data suggests that it has a significant negative association with the *novelty score* and the *creativity score* but a significant positive association with *knowledge and experiences.* This means that the more knowledgeable and experienced the participants tend to produce more appropriate uses. However, the more appropriate the ideas are, the less novel and less creative they were.

Regarding the *novelty score*, the data suggests that it has a significant positive association with the *creativity score* but a significant negative association with *knowledge and experience.* This means that the participants with more knowledge and experience generated ideas that are less novel. The association also shows that the more novel the ideas are, the more creative they will be.

Regarding the *extraversion* personality traits, the data suggests that it has a significant negative association with *creative potential.* This means participants with low extraversion scores tend to have more creative potential. The data also suggests that the participants who are high on the *neuroticism* personality scale have a stronger *creative personality.*

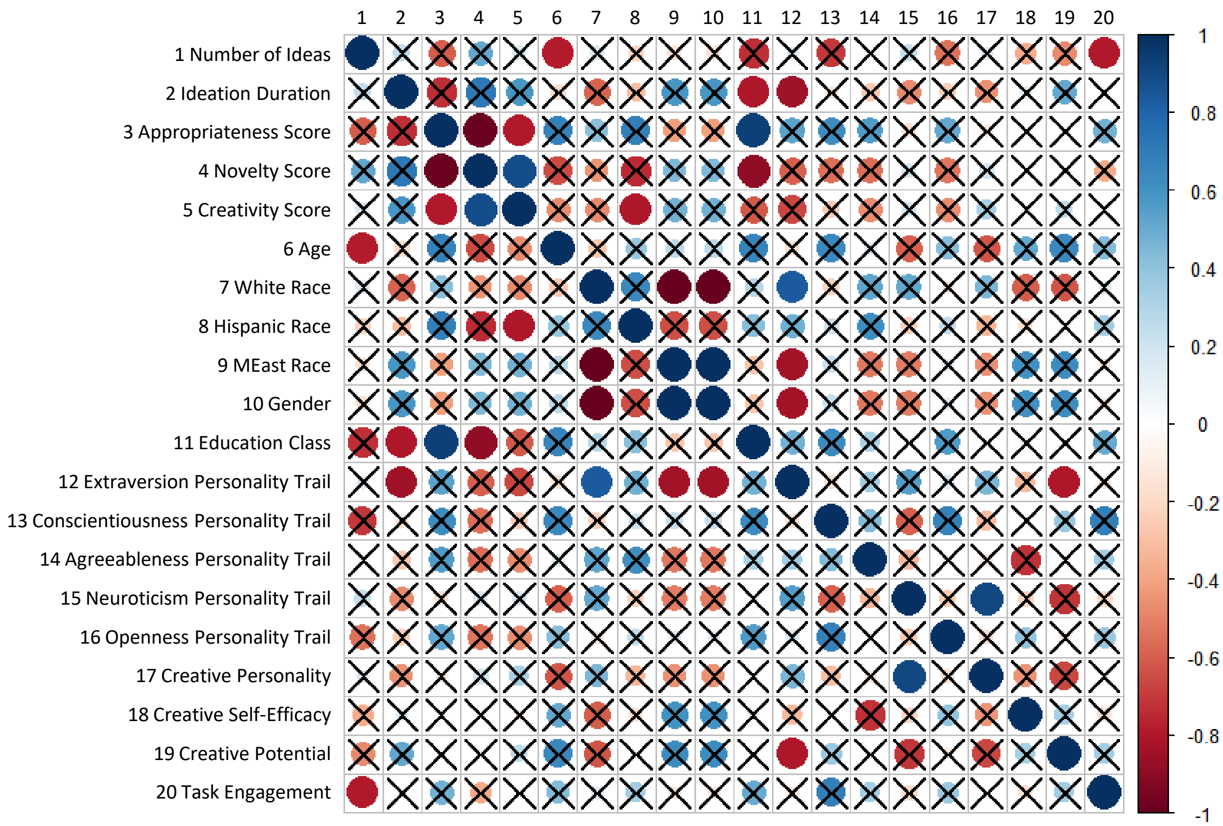

Figure 47: Pearson correlation between the personal characteristics (age, gender, race, knowledge and experience, general personality, creative personality, creative self-efficacy, and creative potential), task engagement, and creative performance on the given task.

5.6.3 RQ4.2: How do semantic cues affect creative performance?

The performance of the participants on the creativity task is shown visually in Figure 48. The figure reports 6 measures, namely, (i) the mean number of valid ideas generated by participants, (ii) the mean creativity score on the given task, (iii) the mean ideation duration of each participant in addition to the grand mean, (iv) the mean appropriateness score for the generated valid responses for each participant in addition to the grand mean, (v) the mean novelty score for the generated valid responses for each participant besides the grand mean, and (vi) the mean creativity score for the generated valid responses for each participant besides the grand mean. These measures will be used to validate the 6 posed hypotheses in Section 5.2.

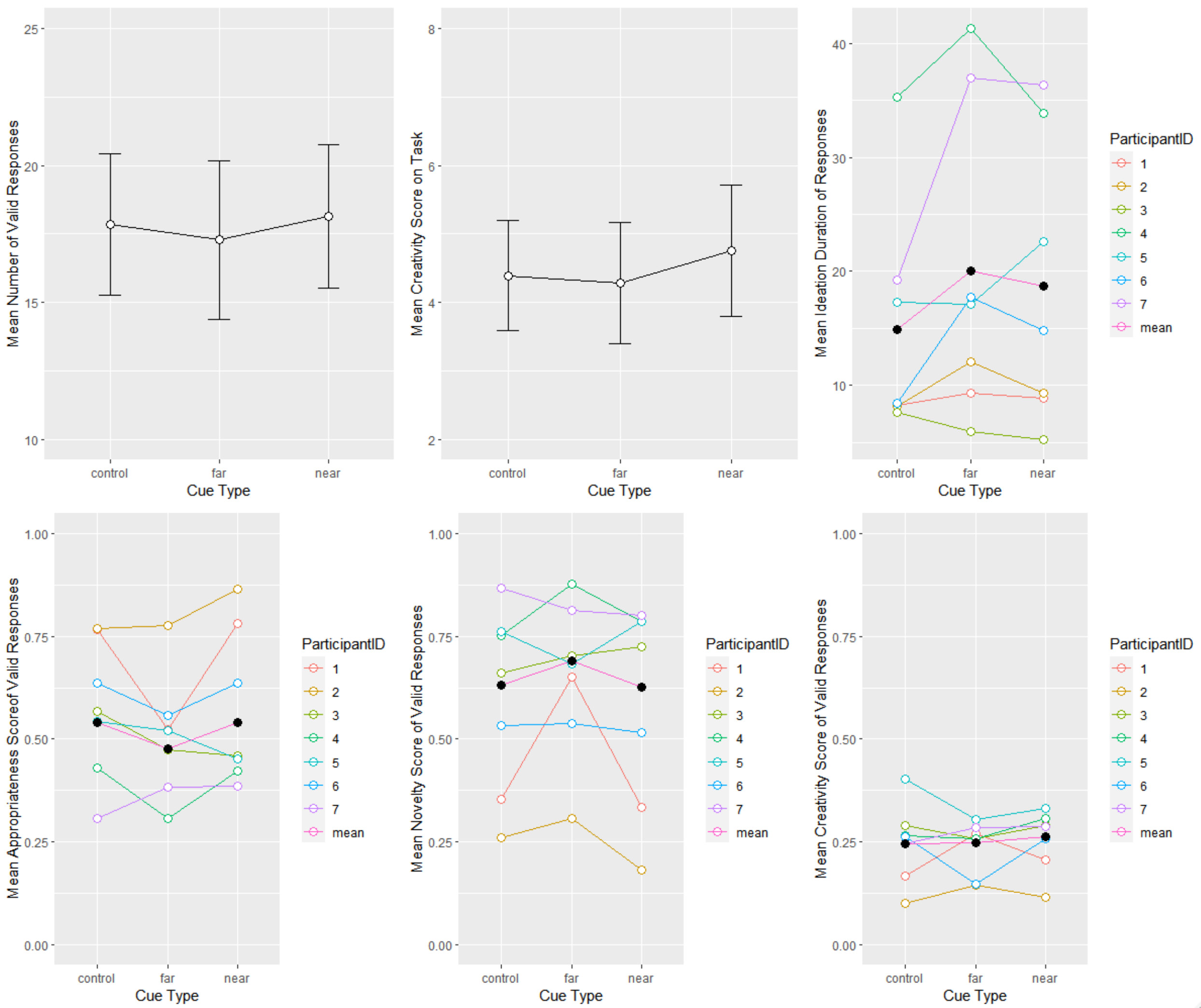

Figure 48: A visual depiction of the six measures used to assess the creative performance of the participants on the given task.

Regarding the *number of valid responses*, the results from the Shapiro-Wilk test indicate that the data under the three conditions: control, far, and near are normally distributed (W=.88, .89, .86; p=.2, .3, .1, respectively). This means that the one-way

ANOVA test can be used to check for significance. The results obtained from the ANOVA test indicate that there is no significant difference in the number of valid responses the participants provided under the different conditions ($F(2,6)=.03$, $p=.97$). This means that there is not enough evidence to support the 1st alternative hypothesis, $H_A^{1\text{-}1}$, presented in Table 7, which states that distinct types of cues can affect the number of generated valid responses.

Regarding the *creativity scores on the test*, the results from the Shapiro-Wilk test indicate that the under the three conditions: control, far, and near are normally distributed ($W=.89$, $.90$, $.84$; $p=.3$, $.3$, $.1$, respectively). This means that the one-way ANOVA test can be used to check for significance. The results obtained from the ANOVA test indicate that there is no significant difference in the creativity scores that the participants achieved under the different conditions ($F(2,6)=.08$, $p=.92$). This means that there is not enough evidence to support the 2nd alternative hypothesis, $H_A^{1\text{-}2}$, presented in Table 7, which states that distinct types of cues can affect the creativity scores on the given task.

Regarding the *ideation duration of the responses*, after fitting the data into a linear regression model using the hierarchical linear modeling (HLM) technique to strip out the variance introduced through individual differences, the contributions of the far and near cues were not significant. The estimated β_b for the far cues was 5.2±2.8 seconds (t(8.1)=1.86, p=.1) more than the one for the no cue while the estimated β_c for the near cues was 3.8±2.6 seconds (t(6.7)=1.47, p=.2) more than the one for the no cue. This means that there is not enough evidence to support the 3rd alternative hypothesis, $H_A^{1\text{-}3}$, presented in Table 7 and that no cue type is significantly different in stimulating the participants to produce responses faster.

Regarding the *appropriateness of the generated valid responses*, after fitting the data into a linear regression model using the technique, the contributions of the far and near cues were not significant. The estimated β_b for the far cues was - .071±.041 (t(6.3)=- 1.7, p=.1) less than the one for the no cue while the estimated β_c for the near cues was - .0006±.031 (t(6.1)=- .02, p=.98) less than the one for the no cue. This means that there is not enough evidence to support the 5th alternative hypothesis, $H_A^{1\text{-}5}$, presented in Table 7 and that no cue type is significantly different in stimulating the participants to produce more appropriate responses.

Regarding the *novelty of the generated valid responses*, after fitting the data into a linear regression model using the technique, the contributions of the far and near cues were not significant. The estimated β_b for the far cues was .064±.049 (t(5.8)=1.3, p=.2) more than the one for the no cue while the estimated β_c for the near cues was

- .007±.033 (t(34.2)=- .2, p=.8) less than the one for the no cue. This means that there is not enough evidence to support the 4th alternative hypothesis, $H_A^{1\text{-}4}$, presented in Table 7 and that no cue type is significantly different in stimulating the participants to produce more novel responses.

Regarding the *creativity of the generated valid responses*, after fitting the data into a linear regression model using the technique, the contributions of the far and near cues were not significant. The estimated β_b for the far cues was .002±.025 (t(4.6)=.1, p=.9) more than the one for the no cue while the estimated β_c for the near cues was .017±.017 (t(11.8)=.96, p=.4) more than the one for the no cue. This means that there is not enough evidence to support the 6th alternative hypothesis, $H_A^{1\text{-}6}$, presented in Table 7 and that no cue type is significantly different in stimulating the participants to produce more creative responses.

5.6.4 RQ4.3: How do semantic cues affect brain behavior?

Answering RQ4.3: How do semantic cues affect brain behavior? requires eliciting the ERPs from the EEG data of the individual participants by following the process outlined in Section 5.1.4 and Section 5.3.4. Upon doing so, the EEG data for two participants turned out to be corrupted, which means that the EEG data of only 5 participants will be used in answering RQ3. Figure 49 shows the ERPs exerted by the participants (a) after showing the three types of cues and (b) after showing the associated objects for which they were asked to generated alternative uses. The figure presents the brain activity for the electrode sites where the measures of interests are maximal, as described in Section 5.3.4. These sites are (i) Pz for the P3 component, (ii) Fz and AFz for the midfrontal old-new (MFON) component of the old-new probe paradigm, and (iii) P3 and P7 for the left-parietal old-new (LPON) component of the old-new probe paradigm. The mean amplitudes between the latencies for each of the 3 components mentioned above, i.e., P3, MFON, and LPON measured on the site where the component is maximal, are shown in Figure 50.

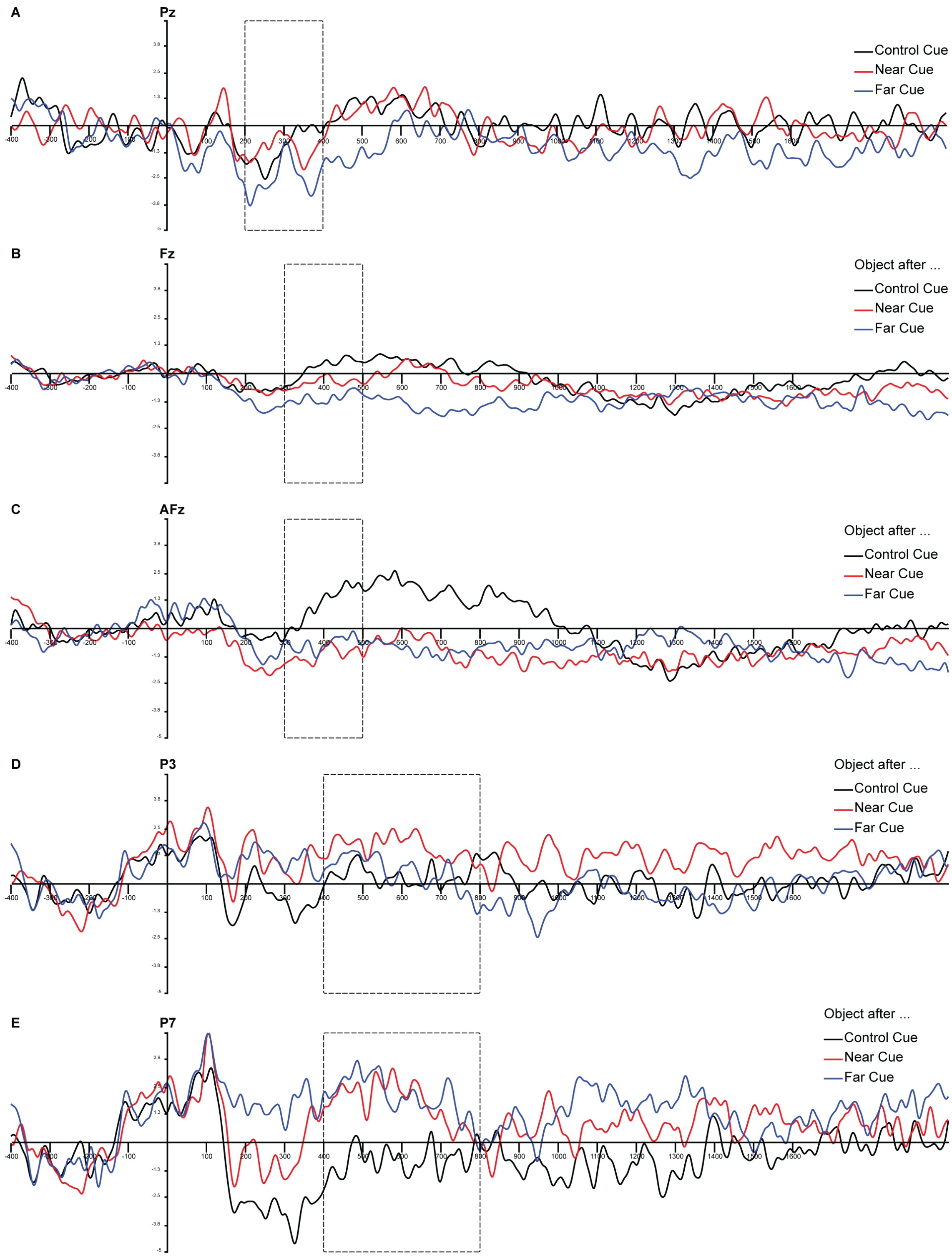

Figure 49: Grand ERPs exerted by the participants after showing the cues (plot A) and after showing the objects (plots B-E). The dashed boxes represent the investigation areas of interest for any significant differences between the different treatments.

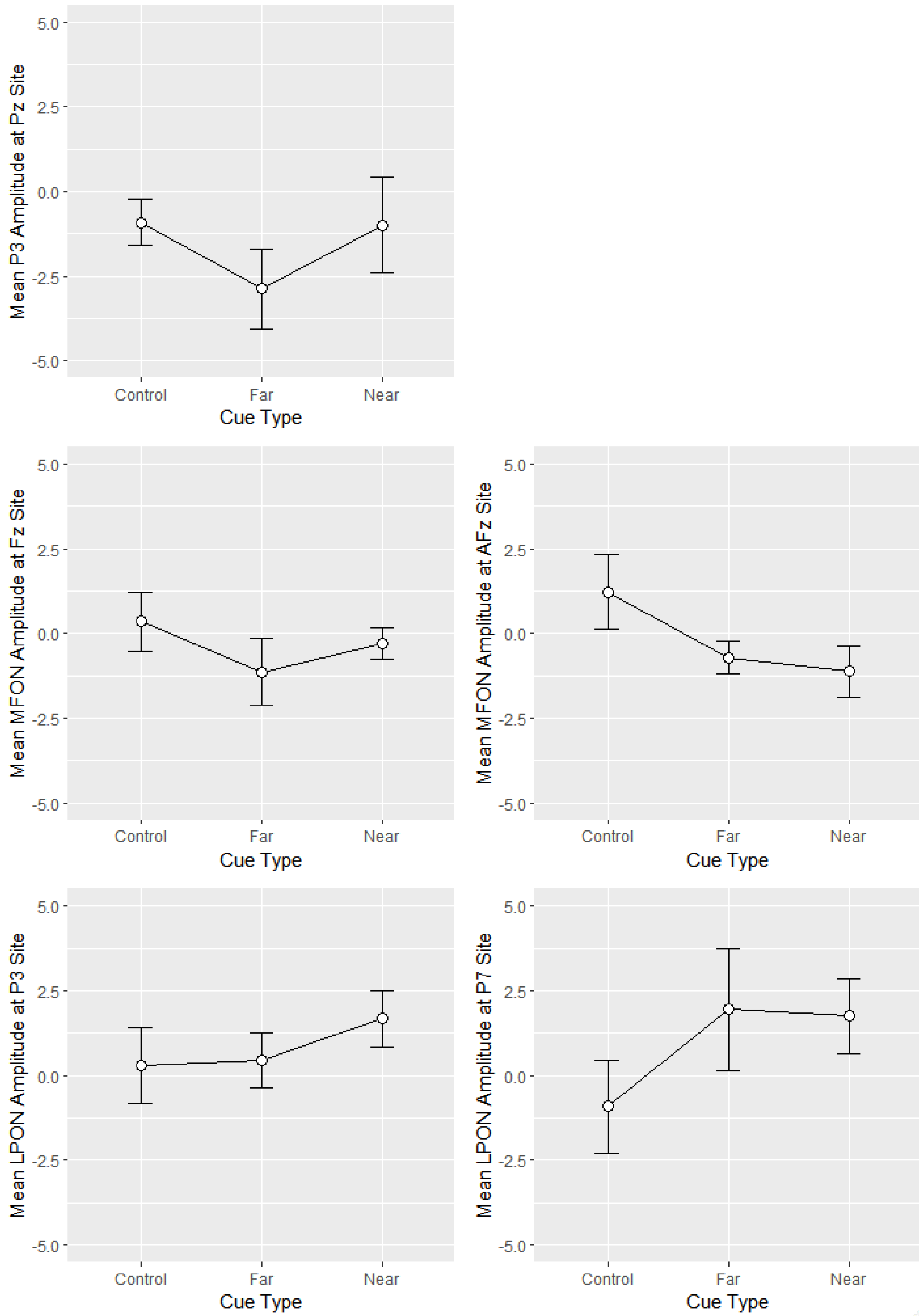

Figure 50: The mean amplitude for the three components of interests (P3 at the top, MFON in the middle, and LPON at the bottom) measured at the corresponding sites where the signal is maximal.

Regarding the *P3* component measured on the Pz site, the results from the Shapiro-Wilk test indicate that the data under the three conditions: control, far, and near are normally distributed (W=.90, .81, .95; p=.4, .1, .7, respectively). This means that the one-way ANOVA test can be used to check for significance. The results obtained from the ANOVA test indicate that there is no significant difference in the mean amplitude of the P3 component (the interval between 200-400 ms) exerted by the participants under the different conditions ($F(2,4)=.93$, $p=.4$). This means that there is not enough evidence to support the 1st alternative hypothesis, $H_A^{2\text{-}1}$, presented in Table 7, which states that familiarity with the distinct types of cues will be different as measured by the amplitudes of the P3 component on the Pz site.

Regarding the *midfrontal old-new* (MFON) component of the old-new probe paradigm measured on the *Fz* site, the results from the Shapiro-Wilk test indicates that the data under the three conditions: control, far, and near are not normally distributed (W=.88, .76, .66; p=.3, .04, .004, respectively). The results obtained from the Kruskal-Wallis test indicate that there is no significant difference in the mean amplitude of the MFON component (the interval between 300-500 ms) exerted by the participants on the Fz site under the different conditions ($\chi^2(2, N=4)=.42$, $p=.8$). This means that there is not enough evidence to support the 2nd alternative hypothesis, $H_A^{2\text{-}2}$, presented in Table 7, which states that recognizing different types of cues as related to the shown object will be different as shown via the mean amplitude of MFON component when measured on the Fz site.

Regarding the *midfrontal old-new* (MFON) component of the old-new probe paradigm as measured on the *AFz* site, the results from the Shapiro-Wilk test indicates that the data under the three conditions: control, far, and near are normally distributed (W=.86, .84, .83; p=.2, .2, .1, respectively). This means that the one-way ANOVA test can be used to check for significance. The results obtained from the ANOVA test indicate that there is no significant difference in the mean amplitude of the MFON component (the interval between 200-400 ms) exerted by the participants on the AFz site under the different conditions ($F(2,4)=2.33$, $p=.1$). This means that there is not enough evidence to support the 3rd alternative hypothesis, $H_A^{2\text{-}3}$, presented in Table 7, which states that recognizing different types of cues as related to the shown object will be different as shown via the mean amplitude of MFON component when measured on the AFz site.

Regarding the *left-parietal old-new* (LPON) component of the old-new probe paradigm as measured on the *P3* site, the results from the Shapiro-Wilk test indicates that the data under the three conditions: control, far, and near are normally distributed (W=.95, .97, .93; p=.7, .9, .6, respectively). This means that the one-way ANOVA test can be used to check for significance. The results obtained from the ANOVA test indicate that there is no significant difference in the mean amplitude of the LPON component (the interval between 400-800 ms) exerted by the participants on the P3 site under the different conditions (F(2,4)=0.67, p=.5). This means that there is not enough evidence to support the 4th alternative hypothesis, $H_A^{2\text{-}4}$, presented in Table 7, which states that utilizing the cues to come up with uses for the shown objects will be different as shown via the mean amplitude of LPON component when measured on the P3 site.

Regarding the *left-parietal old-new* (LPON) component of the old-new probe paradigm as measured on the *P7* site, the results from the Shapiro-Wilk test indicates that the data under the three conditions: control, far, and near are normally distributed (W=.99, .96, .88; p=.97, .7, .3, respectively). This means that the one-way ANOVA test can be used to check for significance. The results obtained from the ANOVA test indicate that there is no significant difference in the mean amplitude of the LPON component (the interval between 400-800 ms) exerted by the participants on the P7 site under the different conditions (F(2,4)=1.21, p=.3). This means that there is not enough evidence to support the 5th alternative hypothesis, $H_A^{2\text{-}5}$, presented in Table 7, which states that utilizing the cues to come up with uses for the shown objects will be different as shown via the mean amplitude of LPON component when measured on the P7 site.

5.7 Discussion

This section discusses the findings of each research question in a separate subsection and compares the findings with those found in the literature.

5.7.1 RQ4.1: What is the relationship between (a) personal characteristics: biological factors, knowledge and experience, personality, creative self-efficacy, and creative potential; (b) task engagement; and (c) creative performance?

The results from the correlation study performed to investigate the relationship between the factors of interest in RQ4.1: What is the relationship between (a) personal characteristics: biological factors, knowledge and experience, personality, creative self-efficacy, and creative potential; (b) task engagement; and (c) creative performance? showed there are significant associations between different measures of each factor. There is a significant strong association between the *personal characteristics* as measured via age, race, knowledge and experience, and extraversion personality traits with the creative performance measured on the number of valid ideas generated, ideation duration, appropriateness score, novelty score, and creativity score. Out of these associations, only the knowledge and experience factor has a significant strong association with three measures of the creative performance, namely, ideation duration (negative association), appropriateness score (positive association), and novelty score (negative association). In other words, the more knowledge and experience the subjects have, (a) the less time they will spend ideating on creative tasks such as the one used in this study, and (b) the more appropriate but fewer novel ideas they will produce. This is consistent with what is found in the literature that deep knowledge and experience can impede creativity if not accompanied with intellectual flexibility and openness (Bourgeois-Bougrine et al., 2020; Corazza & Agnoli, 2018; Kraft, 2005; Webb et al., 2018) and hence turns into a curse as Pinker (2014) is calling it.

Although the correlation study showed a moderate association between the *openness* personality trait and three of the creative performance measures, namely, the number of ideas generated (negative association), appropriateness score (position association), novelty score (negative association), and creativity score (negative association), none of them were significant. Not considering significance, this means that the subjects with more open personalities tend to generate more appropriate but less novel and creative ideas. This contradicts what has been stated earlier in the previous paragraph, but the reader should be reminded that these findings are not based on significant results and cannot be taken for granted. Also, the reader should be reminded that the findings were based on a creative performance task, i.e., the alternative use task, which measures the creative potential, and such findings may not necessarily reflect the future creative performance of the individuals.

Like the associations found between the openness personality trait and the measures of creative performance, the other personality traits, i.e., extraversion, agreeableness, conscientiousness, and neuroticism, although mostly not significant, have moderate to strong associations with the measures of the creative performance. For example, there is a strong association between the *extraversion* trait and four out of the five measures of the creative performance, namely, ideation duration (significant negative association), appropriateness score (insignificant positive association), novelty score (insignificant negative association), and creativity score (insignificant negative association). This means that the extraverted subjects tend to spend less time generating more appropriate ideas but less novel and less creative.

Similarly, there is a strong but insignificant association between the *agreeableness* personality trial and 3 out of the 5 measures of the creative performance, namely, number of generated valid ideas (negative association), appropriateness score (positive association), and novelty score (negative association). This means that more agreeable individuals tend to produce fewer valid ideas that are more appropriate but less novel. The *conscientious* personality trait also has strong but insignificant associations with three out of the five measures of creative performance, namely, appropriateness score (positive association), novelty score (negative association), and creativity score (negative association). This means that more conscious individuals tend to generate more appropriate ideas but less novel and less creative. On the other hand, the *neuroticism* personality trait has strong negative but insignificant associations with only one out of the five measures of the creative performance, namely, ideation duration. This means that more neurotics subjects tend to spend less time ideating.

Age as a biological personality factor has strong associations with three out of the five measures of the creative performance, namely, number of generated valid ideas (significant negative association), appropriateness score (insignificant positive association), and novelty score (insignificant negative association). This means that older individuals tend to generate fewer valid ideas that are more appropriate but less novel. Age also has a moderate negative association with creativity score, but the association is not significant. This is related to the discussion mentioned earlier that deep knowledge and experience should be accompanied by openness for creativity to sprout. Since age is usually a good determinate of knowledge and experience (also shown through the correlation study via a strong but insufficient association), the same discussion can be raised again here.

Opposite to the other personal characteristics, *creative personality*, *creative self-efficacy*, and *creative potential* have weak to moderate insignificant association with a maximum of two of the five measures of creative performance. Creative personality has a week negative association with the ideation duration, meaning that subjects with stronger creative personalities come with ideas faster. Creative self-efficacy has a weak negative association with the number of generated valid ideas meaning that people who believe in their creative abilities more tend to produce a fewer number of valid ideas. On the other hand, creative potential has a moderate negative association with the number of generated valid ideas and a moderate positive association with the ideation duration. This means that subjects who have higher creative potential tend to spend more time producing a fewer number of valid ideas.

The correlation study shows that there is a significant, strong, negative association between *task engagement* and the creative performance measured via the number of valid ideas generated. This means that the less the subjects indicated that they enjoyed the task, the more valid ideas they produced. Although not significant, task engagement also has a moderate positive association with the appropriateness score and a moderate negative association with the novelty score. This means that the less engaged with the task the subjects reported, the more novel but less appropriate ideas they generated. This could be due to the boredom phenomena, which was found to be positivity linked to creativity and curiosity (Hunter, 2015; Hunter, Abraham, Hunter, Goldberg, & Eastwood, 2016).

5.7.2 RQ4.2: How do semantic cues affect creative performance?

Although the claims reported by previous research on the effect of cues on creativity such as the work of Dugosh et al. (2000), Dugosh and Paulus (2005), Perttula et al. (2006), Perttula and Sipilä (2007), and Fu et al. (2013), the findings in this chapter failed to provide such support. Although the mean number of generated valid ideas among subjects in the case of the near cues was higher than the control and far cues, the differences were not statistically significant. Similarly, although the mean creativity score on the task was higher when the participants were presented with near cues than when control or far cues were presented, the differences were not statistically significant.

When moving from the overall mean measures reported in the previous paragraph, i.e., the mean number of valid ideas and the mean creativity score, to the subject-wise scores, the analysis showed similar findings. When the subjects were not shown any cues, the mean duration spent generating ideas was less than when cues were shown, but the differences were not significant. Similarly, the far cues impeded the subjects from generating more appropriate ideas but stimulated them to generate more creative ones; however, the differences are not significant. When considering the creativity score, all near and far cues in addition to the control group yielded close results, and no statistically significant differences were found. It is worth mentioning that some of the participants showed dramatic increases in their novelty score when far cues were shown compared to when no cues or near cues were shown. Other subjects showed a dramatic increase in ideation duration when cues were shown to them. In contrast, others experienced a sharp decline in the appropriateness score when presented with far cues compare to when no cues or near cues were shown.

The inability of this study to reveal any significant differences in the 5 used measures, i.e., the mean number of valid ideas, mean creativity score on task, mean ideation duration, mean appropriateness score, mean novelty score, and mean creativity score if the differences are genuinely existing could be due to the small number of recruited participants. Having a small number of participants, especially if the effect size is small, will make the study less powerful in uncovering any existing differences.

If it is the case that no significant differences genuinely exist between the different types of cues, then the claim that engineering students, who are the only participants in the study, think differently, similar to what Jonczyk et al. (2019) have found, could be a plausible explanation. However, it is difficult to claim that the cause of the failure to find any significant differences is due to the recruited engineering sample since the study does not include any non-engineering participants.

5.7.3 RQ4.3: How do semantic cues affect brain behavior?

Despite that all the analyses of the cortical activities for the different components on the different electrode sites turned out to be statistically insignificant, some of the results seem consistent with the literature when considering the signal on one electrode site but contradicting with the literature when considering it on another electrode site. The measure of the unfamiliarity with the shown cues through the *P3* component on the Pz electrode site came consistent with the literature where the far cues elicited more brainpower than the control and the near cues.

The non-confirmatory with the literature appears with the *old-new probe paradigm* (ONPP) when measuring it on the different suggested sites of the maximal signal. As explained in Section 5.1.4, ONPP has two effects: the midfrontal old-new (*MFON*) effect and the left-parietal old-new (LPON) effect. Although not statistically significant, the MFON effect came consistent with the literature. The magnitude of the signal on the Fz electrode site was more negative for the new probes (the far cues) than for the old probes (the near cues). However, the same behavior was not recorded on the AFz electrode site—the opposite was observed where the magnitude was less negative for the new probes (the far cues) than for the old probes (the near cues).

The same contradicting behavior was observed for the *LPON* effect, although the differences were not also statistically significant. On the P3 electrode site, the magnitude of the signal was higher for the old probes (the near cues) than for the new probes (the far cues), as expected and reported in the literature. However, the same behavior was not observed when measuring the signal on the P7 electrode site—the magnitude of the signals for both the old probes (the near cues) and the new probes (the far cues) was very close, i.e., the signals were intertwining and crossing each other as shown in Figure 49.

5.8 Opportunities and Future Work

Given the COVID-19 situation during which this study was conducted, one of the obstacles was the restriction on bringing *participants* to the lab to do the EEG part of the study. Due to the precautions that people need to take while they are close to each other, like what usually happens when conducting an EEG experiment, the decision to only recruit 7 participants to take part in the study was wiser despite the low power that the study may suffer (and is actually suffering) from. When the situation goes back to normal, one of the top future works is to recruit more participants. The recruitment should also not only be restricted to engineering students. Still, it should also be extended to non-engineering to allow for a more precise understanding of the differences between engineering and non-engineering.

Regarding the *design of the EEG experiment*, one reasonable future modification is to increase the number of objects in the practice part from one to three objects, i.e., from 3 to 9 trials, and in the main part from 25 to 30 objects, i.e., from 75 to 90 trials. This will make it more flexible to drop any slightly noisy trials when processing the raw EEG data, which will result in more clear ERPs. Increasing the number of tails in the practice part of the study is meant to make the participants more comfortable with the experiment. However, such an increase in the number of trials in the practice part and the main part may require breaking the entire experiment into at least two parts. Despite the extra effort that will be introduced, breaking the experiment into multiple parts has two advantages. First, the participants will have the chance to take a short break to restore their focus and enhance their energy. Second, having the experiment in multiple parts means that the EEG recordings will be broken down into multiple files. Such practice will allow the researcher to check the quality of the EEG signals before the start of each part to conduct any necessary adjustments. Also, this will reduce the probability of losing all the data of any single participant and make the data easy to transfer and work with.

Regarding the self-report measures that accompanied the study, the *knowledge and experience measure,* which was based on the participant's class level, was not detailed enough to reflect the participants' exact level of knowledge and experience. Using the class level as a proxy to knowledge and experience was considered to avoid boredom that may arise when filing the lengthy knowledge and experience surveys currently available in the literature. This was of particular concern to this study because the participants who agreed to participate in the study were volunteering, i.e., not paid. In the future, a more elaborated survey that balance the length and the details about the participant knowledge and experiment will be considered. The more details that can be gain about the participants' knowledge and experiences, the more informative the results will be.

Like the measure used for knowledge and experience, the survey used to measure the *level of engagement* of the participants with the given task was not very detailed. A more detailed survey and possibility with few open-ended questions, despite the extra effort to code and analyze the answers to these open-ended questions, is a viable option. Having a deep understanding of the participants' engagement shown while working on the task could be of immense help when different creativity scores are observed. Besides having a more detailed survey to measure the participants' engagement with the task, a short debriefing session at the end of the experiment can be used instead. Like the open-ended questions, the debriefing sessions will require more time for analysis to be performed but are guaranteed to give deeper insight into the participants' engagement with the performed task.

6

CONCLUSION

"It is easier to tone down a wild idea than it is to think up a new one."

—Alex Osborn

6.1 Overall Summary of All Research Questions

The dissertation targeted four aspects of the creativity topic: the *definition aspect* (Chapter 2), the *models aspect* (Chapter 3), the *factors aspect* (Chapter 4), and the *engineering aspect* (Chapter 5) and a total of 11 research questions, presented in Figure 2, were answered. On the *definition aspect*, the dissertation took a data-driven approach and analyzed 170 definitions of creativity from both the engineering and generic literature to propose an adequate comprehensive one. On the *models aspect*, a framework that classifies the vast landscape of creative models into 5 categories was proposed. The framework's purpose was to equip the creativity researchers, especially the starting researchers, with a tool that they can utilize to navigate through the vast number of creativity models that already exist in the literature. On the *factors aspect*, the dissertation provided the factors models framework. This framework classifies the different factors that affect creativity into 3 major categories that give the researchers the confidence to place the work they come across in the creativity literature into one of these categories based on the factors being investigated in the work being inspected.

On the *engineering aspect*, 11 factors that are thought to generally affect creativity were within engineering. An experiment was designed and run with the help of 7 participants from the Gallogly College of Engineering, the University of Oklahoma. The experiment was accompanied by a study of the participants' brain activity using electroencephalography (EEG) and Event-Related Potentials (ERPs) to gain more insights into the brain-behavior under different conditions.

The opportunities and the future work related to the 4 target aspects of creativity were discussed at the end of each respected chapter. The opportunities presented there either stem from a limitation in the methodology used due to time constraints or represent ideas of interest that one can further investigate in the future.

6.2 Summary of Individual Research Questions

6.2.1 RQ1: What is creativity?

The analysis of the 42 creativity definitions collected from engineering literature and 124 creativity definitions from generic literature show that the top 44% of the terms used to define creativity in engineering are also used in the generic literature. These include terns such as "idea," "solution," "product," "produce," "process," "original," "idea," and "ability." Terms such as "quality," "people," "novelty," and "generate" are only frequently in engineering literature, while terms such as "solve," "skill," "experience," "critical," and "approaches" are only frequently used in generic literature. The term "critical" appears very frequently in the generic literature (in more than 40% of the definitions); however, it was completely missing from the most frequently used terms in creativity definitions in the engineering corpus. Section 2.6.1 provides a detailed discuss of the terms used in engineering literature while Section 2.6.2 gives a detailed discussion of the terms used in generic literature.

Given the practical nature of engineering, it comes with no surprise that the scholars, when defining creativity in engineering, emphasize terms such as “quality” and “novelty,” which represent the heart of the characteristic theme. On the other hand, it is also no surprise that the definitions in the generic corpus focus on terms such as “experience,” “critical,” and “approaches,” which are linked with the process theme and the mental process theme. These themes focus on the steps required to form creative ideas and how these ideas come to existence in the creative person’s head.

When taking into consideration the analysis performed on the definitions from the engineering and generic literature (Chapter 2) as well as the results obtained to the research questions posed in Chapter 3: Creativity Models and Chapter 4: Creativity Factors, a set of aspects seems to be missing or not being emphasized on when defining creativity. Many definitions (see Figure 19) use the term “idea” when defining creativity. However, the term “idea” does not capture all the forms of production that people can generate. Using the term “idea” when addressing creativity excludes the other forms of human outcomes representing the manifestation of these ideas, such as artworks and product prototypes.

Besides the exclusivity problem that stems from using the term “idea” when defining creativity, most definitions are missing the social aspect. The two-way reaction between the creative outcome and society, i.e., the effect of the creative outcome on society and the collective reaction of the society toward the creative outcome, undoubtedly plays a role in defining what is accepted as a creative outcome. Although the social circle may expand or contract based on the level of creativity being addressed, as shown in Chapter 3: Creativity Models, the idea being raised here is that society is not a significant aspect being focused on when defining creativity. The social aspect has been alluded to in the engineering literature by using the "people" term in about 10% of the definitions. Although no similar indications have been found in the most frequent words used to define creativity in the generic literature, the results obtained through topic modeling showed a trait of such aspect in Topic 6 (see Figure 17). The trail is indicated through the term "judge," which is usually performed by an outside entity that usually belongs to the society where the creative outcome was produced.

Based on the discussion provided above, any adequate definition for creativity should cover five themes: the product theme, the process theme, the characteristic theme, the mental process theme, and the social theme. In addition, the definition should take into consideration that creativity is not a single thing and that it can take different levels that range from creativity recognized by the individual her/himself only to the eminent creativity being recognized by a large group of people as described in details in

Chapter 3: Creativity Models. Although it may not be directly related, any definition for creativity needs to consider the varied factors that may affect creativity, as described in detail in Chapter 4: Creativity Factors. Taking all these points into consideration and after several iterations and reflections on the topic, the following definition for creativity shown in the box below has emerged.

> Creativity is a **deliberate process** to produce an **act** that is at <u>minimum</u> **novel** and **useful** to the **circle** in which it was introduce, even after a while.

The definition emphasis (a) the product theme by using the term "act;" (b) the process theme by using the term "process;" (c) the characteristic theme by using the terms "novel" and "useful" and indicating their necessity beside other characteristics using the term "minimum;" (d) the mental process theme by using the term "deliberate" as a quality of the process; and (e) the social theme by using the term "circle."

6.2.2 RQ2: What models of creativity exist?

Creativity models can be classified into five main categories: Level Models, Thematic Models, Process Models, Mental Models, and Ecological Models. The Level Models are concerned with classify creativity into different types and levels, e.g., little-c creativity and Big-C creativity. Thematic Models are concerned with organize the landscape of creativity research into different themes, e.g., process, person, and press. Process Models focuses on explaining the creative process, i.e., the steps involved in producing a creative act. Similar to the Process Models, Mental Models focuses on mental process that goes into the head of the creator when the production of the creative act occurs. Ecological Models are concern with investigating the relationship between the creative performance and the numerous factors affecting it.

The creativity framework within which the above findings are reported is that a creative act must be at least (a) *novel*, unprecedented in the society in which the act was introduced and is not copied from somewhere else by the creator, and (b) *useful*, to some degree, to the society in which it was introduced judged by the society itself immediately or after a while (Batey, 2012; Craft, 2001; D. H. Cropley & Kaufman, 2012; Lee et al., 2012; Mayer, 2014; Mumford, 2003; Runco & Jaeger, 2012; Said-Metwaly et al., 2017a; Zeng et al., 2009). Regardless of the widespread agreement that novelty and usefulness represent the bare minimum requirements for an act to be labeled creative, the exact definition for novelty and usefulness is debatable (Batey, 2012; Batey & Furnham, 2006; Runco & Jaeger, 2012).

6.2.3 RQ3: What factors affect creativity?

The factors that affect creativity can be classified into three main categories: factors related to the Personal Characteristics, factors related to the Environmental Characteristics, and factors related to the Approaches and Tools being used. The factors related to the Personal Characteristics are concerned with the characteristics that define the individual's personality (identity) and can be further classified into factors related to the Biological Characteristics and factors related to the Non-biological Characteristics. The Biological Characteristics include factors such as age, sex/gender, and race/ethnicity. The Non-biological Characteristics include factors such as domain-specific knowledge and experience, intrinsic motivation, and creative personality (for details, see Section 4.6.1.1).

Environmental Characteristics represent all the factors surrounding the individual and are usually outside of the individual's control. The environmental factors can be divided into 3 sets: social, physical, and virtual. The social set includes factors such as home, friends/peers, and school/work. The physical set includes factors related to the design of the physical environment within which the individual works such as the existence of the natural elements and cues. The virtual set includes factors related to designing the virtual environment with which the individual interacts (for details, see Section 4.6.1.2).

Factors related to the Approaches and Tools represent the set of approaches and tools that the individual follows and uses to solve a given creative problem. When correctly followed such approaches and tools can help individuals to generate creative solutions. Some of the approaches claimed to enhance creativity are Wallas 4-Stage Model and Osborn-Parnes Creative Problem-Solving Model. Some of the tools claimed to help in generating creative acts are Brainstorming, Synectic, and Morphological Chart (for details, see Section 4.6.1.3).

6.2.4 RQ4: How is creativity different in engineering?

The correlational study performed on seven engineering students (age = 29.2±4.4 years old; 29% female) from the Gallogly College of Engineering, the University of Oklahoma indicates that there is a significant strong association between the personal characteristics as measured via age, race, knowledge and experience, and extraversion personality traits with the creative performance measured on the number of valid ideas generated, ideation duration, appropriateness score, novelty score, and creativity score. Out of these associations, only the knowledge and experience factor has a significant strong association with three measures of the creative performance, namely, ideation duration (negative association), appropriateness score (positive association), and novelty score (negative association). In other words, the more knowledge and experience the subjects have, (a) the less time they will spend ideating on creative tasks such as the one used in this study, and (b) the more appropriate but fewer novel ideas they will produce. This is consistent with what is found in the literature that deep knowledge and experience can impede creativity if not accompanied with intellectual flexibility and openness (Bourgeois-Bougrine et al., 2020; Corazza & Agnoli, 2018; Kraft, 2005; Webb et al., 2018) and hence turns into a curse as Pinker (2014) is calling it.

Although the correlation study showed a moderate association between the *openness* personality trait and three of the creative performance measures, namely, the number of ideas generated (negative association), appropriateness score (position association), novelty score (negative association), and creativity score (negative association), none of them were significant. Not considering significance, this means that the subjects with more open personalities tend to generate more appropriate but less novel and creative ideas. This contradicts what has been stated earlier in the previous paragraph, but the reader should be reminded that these findings are not based on significant results and cannot be taken for granted. Also, the reader should be reminded that the findings were based on a creative performance task, i.e., the alternative use task, which measures the creative potential, and such findings may not necessarily reflect the future creative performance of the individuals.

Like the associations found between the openness personality trait and the measures of creative performance, the other personality traits, i.e., extraversion, agreeableness, conscientiousness, and neuroticism, although mostly not significant, have moderate to strong associations with the measures of the creative performance. For example, there is a strong association between the *extraversion* trait and four out of the five measures of the creative performance, namely, ideation duration (significant negative association), appropriateness score (insignificant positive association), novelty score (insignificant negative association), and creativity score (insignificant negative association). This means that the extraverted subjects tend to spend less time generating more appropriate ideas but less novel and less creative.

Similarly, there is a strong but insignificant association between the *agreeableness* personality trial and 3 out of the 5 measures of the creative performance, namely, number of generated valid ideas (negative association), appropriateness score (positive association), and novelty score (negative association). This means that more agreeable individuals tend to produce fewer valid ideas that are more appropriate but less novel. The *conscientious* personality trait also has strong but insignificant associations with three out of the five measures of creative performance, namely, appropriateness score (positive association), novelty score (negative association), and creativity score (negative association). This means that more conscious individuals tend to generate more appropriate ideas but less novel and less creative. On the other hand, the *neuroticism* personality trait has strong negative but insignificant associations with only one out of the five measures of the creative performance, namely, ideation duration. This means that more neurotics subjects tend to spend less time ideating.

Age as a biological personality factor has strong associations with three out of the five measures of the creative performance, namely, number of generated valid ideas (significant negative association), appropriateness score (insignificant positive association), and novelty score (insignificant negative association). This means that older individuals tend to generate fewer valid ideas that are more appropriate but less novel. Age also has a moderate negative association with creativity score, but the association is not significant. This is related to the discussion mentioned earlier that deep knowledge and experience should be accompanied by openness for creativity to sprout. Since age is usually a good determinate of knowledge and experience (also shown through the correlation study via a strong but insufficient association), the same discussion can be raised again here.

Opposite to the other personal characteristics, *creative personality*, *creative self-efficacy*, and *creative potential* have weak to moderate insignificant association with a maximum of two of the five measures of creative performance. Creative personality has a week negative association with the ideation duration, meaning that subjects with stronger creative personalities come with ideas faster. Creative self-efficacy has a weak negative association with the number of generated valid ideas meaning that people who believe in their creative abilities more tend to produce a fewer number of valid ideas. On the other hand, creative potential has a moderate negative association with the number of generated valid ideas and a moderate positive association with the ideation duration. This means that subjects who have higher creative potential tend to spend more time producing a fewer number of valid ideas.

The correlation study shows that there is a significant, strong, negative association between *task engagement* and the creative performance measured via the number of valid ideas generated. This means that the less the subjects indicated that they enjoyed the task, the more valid ideas they produced. Although not significant, task engagement also has a moderate positive association with the appropriateness score and a moderate negative association with the novelty score. This means that the less engaged with the task the subjects reported, the more novel but less appropriate ideas they generated. This could be due to the boredom phenomena, which was found to be positivity linked to creativity and curiosity (Hunter, 2015; Hunter et al., 2016).

Although the claims reported by previous research on the effect of cues on creativity such as the work of Dugosh et al. (2000), Dugosh and Paulus (2005), Perttula et al. (2006), Perttula and Sipilä (2007), and Fu et al. (2013), the findings in this chapter failed to provide such support. Although the mean number of generated valid ideas among subjects in the case of the near cues was higher than the control and far cues, the differences were not statistically significant. Similarly, although the mean creativity score on the task was higher when the participants were presented with near cues than when control or far cues were presented, the differences were not statistically significant.

When moving from the overall mean measures reported in the previous paragraph, i.e., the mean number of valid ideas and the mean creativity score, to the subject-wise scores, the analysis showed similar findings. When the subjects were not shown any cues, the mean duration spent generating ideas was less than when cues were shown, but the differences were not significant. Similarly, the far cues impeded the subjects from generating more appropriate ideas but stimulated them to generate more creative ones; however, the differences are not significant. When considering the creativity score, all near and far cues in addition to the control group yielded close results, and no statistically significant differences were found. It is worth mentioning that some of the participants showed dramatic increases in their novelty score when far cues were shown compared to when no cues or near cues were shown. Other subjects showed a dramatic increase in ideation duration when cues were shown to them. In contrast, others experienced a sharp decline in the appropriateness score when presented with far cues compare to when no cues or near cues were shown.

The inability of this study to reveal any significant differences in the 5 used measures, i.e., the mean number of valid ideas, mean creativity score on task, mean ideation duration, mean appropriateness score, mean novelty score, and mean creativity score if the differences are genuinely existing could be due to the small number of recruited participants. Having a small number of participants, especially if the effect size is small, will make the study less powerful in uncovering any existing differences.

If it is the case that no significant differences genuinely exist between the different types of cues, then the claim that engineering students, who are the only participants in the study, think differently, similar to what Jonczyk et al. (2019) have found, could be a plausible explanation. However, it is difficult to claim that the cause of the failure to find any significant differences is due to the recruited engineering sample since the study does not include any non-engineering participants.

Despite that all the analyses of the cortical activities for the different components on the different electrode sites turned out to be statistically insignificant, some of the results seem consistent with the literature when considering the signal on one electrode site but contradicting with the literature when considering it on another electrode site. The measure of the unfamiliarity with the shown cues through the *P3* component on the Pz electrode site came consistent with the literature where the far cues elicited more brainpower than the control and the near cues.

The non-confirmatory with the literature appears with the *old-new probe paradigm* (ONPP) when measuring it on the different suggested sites of the maximal signal. ONPP has two effects: the midfrontal old-new (*MFON*) effect and the left-parietal old-new (LPON) effect. Although not statistically significant, the MFON effect came consistent with the literature. The magnitude of the signal on the Fz electrode site was more negative for the new probes (the far cues) than for the old probes (the near cues). However, the same behavior was not recorded on the AFz electrode site—the opposite was observed where the magnitude was less negative for the new probes (the far cues) than for the old probes (the near cues).

The same contradicting behavior was observed for the *LPON* effect, although the differences were not also statistically significant. On the P3 electrode site, the magnitude of the signal was higher for the old probes (the near cues) than for the new probes (the far cues), as expected and reported in the literature. However, the same behavior was not observed when measuring the signal on the P7 electrode site—the magnitude of the signals for both the old probes (the near cues) and the new probes (the far cues) was very close, i.e., the signals were intertwining and crossing each other (see Figure 49).

6.3 Contributions

The contributions of this dissertation to literature can be summarized as follows:

- Proposing a data-driven definition for creativity based on the analysis of 42 definitions from engineering literature and 128 definitions from generic literature while talking the systems thinking approach and considering the available models for creativity and factors that affect it.
- Providing a classification of the vast number of models describing creativity and giving example models for each of the five suggested categories (Level Models, Thematic Models, Process Models, Mental Models, and Ecological Models) based on the analysis of tens of creativity related papers.
- Proposing a nested model for the five creativity levels (mini-c creativity, little-c creativity, ed-c creativity, Pro-c creativity, and Big-C creativity) based on the analysis of four level models (2C Model, 3C Model, 4C Model, and 5C Model).

- Proposing an enhanced thematic model for the different strands of creativity (person, process, product, press, measure, persuasion, and potential) based on the analysis of five thematic models (3PM Model, Rhodes 4P Model, Simonton 4P Model, 5P Model, and 6P Model).
- Proposing a simplified process model for creativity that consists of three interconnected steps: problem understanding, divergent thinking and convergent thinking. The proposed model was based a detailed analysis of two process models: Wallas Model and Osborn-Parnes Creative Problem-Solving Model and an overall analysis of several other: Campbell (1960)'s Blind-Variation and Selective-Retention Model of Creative Thought, Simonton (1988)'s Creative Process Model based on Chance-Configuration Theory, (Barron, 1988)'s Psychic Creation Model, Rossman (1931)'s Creativity Model, Osborn (1953)'s Creative Thinking Model, and Kobler and Bagnall (1981)'s Universal Traveler Model.
- Providing a classification of the vast number of the factors affecting creativity giving example factors for each of the three suggested categories (personal characteristics, environmental characteristics, and approaches and tools) based on the analysis of tens of creativity related papers.

- Proposing an ecological model for creativity based on the classification suggested for the creativity models as well as the classification suggested for the creativity factors.
- Investigating the relationship between a set of personal characteristics (biological factors, knowledge and experience, personality, creative self-efficacy, and creative potential), task engagement, and creative performance using a correlation study.
- Investigating the effect of the environmental cues on the creative performance of engineering students via a lab experiment that includes neurological measures (EEG and ERPs) to explain the neurological bases for any differences in observed behavioral performance.

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I
DEMOGRAPHIC QUESTIONNAIRE

The demographic questionnaire used in the experiment outlines in Chapter 5 covers three biological factors, namely, age, gender, and race, and two knowledge/experience factors, namely, class standing and major. The participants were asked to indicate their answers to these factors using the following questionnaire administered online:

What is your age? ________

Which of the following categories best describe you? (select one or more)

- ☐ Asian (for example, Chinese, Filipino, Asian India, Vietnamese, Korean, Japanese, etc.)
- ☐ Black (for example, African American, Jamaican, Haitian, Nigerian, Ethiopian, Somalian, etc.)
- ☐ Hispanic, Latino, or Spanish origin (for example, Mexican or Mexican American, Puerto Rican, Cuban, Salvadorian, Dominican, Colombian, etc.)
- ☐ Middle Eastern or North African (for example, Saudi Arabia, Iranian, Egyptian, Syrian, Libyan, Moroccan, Algerian, Lebanese, etc.)
- ☐ White (for example, German, Irish, English, Italian, Polish, French, etc.)
- ☐ North American Indigenous (for example, Navajo Nation, Blackfeet Tribe, Mayan, Aztec, Native Village of Barrow, Inupiat Traditional Government, Nome Eskimo Community, etc.)
- ☐ Pacific Islander (for example, Native Hawaiian, Samoan, Chamorro, Tongan, Fijian, Marshallese, etc.)
- ☐ Prefer not to say

What is your gender?

- ☐ Male
- ☐ Female
- ☐ Non-binary / third gender
- ☐ Prefer not to say

What is your class standing?

- ☐ Freshman
- ☐ Sophomore
- ☐ Junior
- ☐ Senior
- ☐ Masters
- ☐ Doctorate

What is your major? ____________________

II
PERSONALITY SURVEY

The personality survey used in the experiment outlined in Chapter 5 is based on the Big Five Inventory (BFI) proposed by John et al. (2008). The BFI was administered online and presented to the participants as follows:

In this section, you will be presented with a number of characteristics that may or may not apply to you. For example, do you agree that you are someone who likes to spend time with others? Please, indicate the degree to which you agree or disagree with that statement by selecting a number from 1 (strongly disagree) to 5 (strongly agree).

I see myself as someone who ...

		strongly disagree 1	2	3	4	strongly agree 5
1	is talkative	○	○	○	○	○
2	tends to find fault with others	○	○	○	○	○
3	does a thorough job	○	○	○	○	○
4	is depressed, blue	○	○	○	○	○
5	is original, comes up with new ideas	○	○	○	○	○
6	is reserved	○	○	○	○	○
7	is helpful and unselfish with others	○	○	○	○	○
8	can be somewhat careless	○	○	○	○	○
9	is relaxed, handles stress well	○	○	○	○	○
10	is curious about many different things	○	○	○	○	○
11	is full of energy	○	○	○	○	○
12	starts quarrels with others	○	○	○	○	○
13	is a reliable worker	○	○	○	○	○
14	can be tense	○	○	○	○	○
15	is ingenious, a deep thinker	○	○	○	○	○

I see myself as someone who ...

		strongly disagree 1	2	3	4	strongly agree 5
16	generates a lot of enthusiasm	○	○	○	○	○
17	has a forgiving nature	○	○	○	○	○
18	tends to be disorganized	○	○	○	○	○
19	worries a lot	○	○	○	○	○
20	has a active imagination	○	○	○	○	○
21	tends to be quite	○	○	○	○	○
22	is generally trusting	○	○	○	○	○
23	tends to be lazy	○	○	○	○	○
24	is emotionally stable, not easily upset	○	○	○	○	○
25	is inventive	○	○	○	○	○
26	has an assertive personality	○	○	○	○	○
27	can be cold and aloof	○	○	○	○	○
28	perseveres until the task is finished	○	○	○	○	○
29	can be moody	○	○	○	○	○
30	values artistic, aesthetics expressions	○	○	○	○	○
31	is sometimes shy, inhibited	○	○	○	○	○
32	is considerable and kind to almost everyone	○	○	○	○	○
33	does things efficiently	○	○	○	○	○
34	remains calm in tense situations	○	○	○	○	○
35	prefers work that is routine	○	○	○	○	○

I see myself as someone who ...

		strongly disagree 1	2	3	4	strongly agree 5
36	is outgoing, sociable	○	○	○	○	○
37	is sometimes rude to others	○	○	○	○	○
38	makes plans and follows through with them	○	○	○	○	○
39	gets nervous easily	○	○	○	○	○
40	likes to reflect, play with ideas	○	○	○	○	○
41	has few artistic interests	○	○	○	○	○
42	likes to cooperate with others	○	○	○	○	○
43	is easily distracted	○	○	○	○	○
44	is sophisticated in art, music, or literature	○	○	○	○	○

The set of items in the Big Five Inventory (BFI) associated with each trait of the Big Five Model (BFM) is shown in the table below. This information is required for the quantification process outlined in Section 5.5.1. The symbol "R" indicates that the used item is reversed for the associated trait, and hence its score needs to be reversed before performing the quantification process.

BFM Trait	**# of Associated BFI Items**	**Associated BFI Items**
Extraversion	8	1, 6R, 11, 16, 21R, 26, 31R, 36
Agreeableness	9	2R, 7, 12R, 17, 22, 27R, 32, 37R, 42
Conscientiousness	9	3, 8R, 13, 18R, 23R, 28, 33, 38, 43R
Neuroticism	8	4, 9R, 14, 19, 24R, 29, 34R, 39
Openness to experience	10	5, 10, 15, 20, 25, 30, 35R, 40, 41R, 44

III
CREATIVE PERSONALITY SURVEY

The creative personality survey used in the experiment outlined in Chapter 5 is based on the Creative Personality Scale (CPS) proposed by Gough (1979). The survey was administered online and shown to the participants as follows:

Indicate which of the following adjectives best describe yourself. Check all that apply.

- ☐ Capable
- ☐ Artificial
- ☐ Clever
- ☐ Cautious
- ☐ Confident
- ☐ Egotistical
- ☐ Commonplace
- ☐ Humorous
- ☐ Conservative
- ☐ Individualistic
- ☐ Conventional
- ☐ Informal
- ☐ Dissatisfied
- ☐ Insightful
- ☐ Suspicious
- ☐ Honest
- ☐ Intelligent
- ☐ Well-mannered
- ☐ Wide interests
- ☐ Inventive
- ☐ Original
- ☐ Narrow interests
- ☐ Reflective
- ☐ Sincere
- ☐ Resourceful
- ☐ Self-confident
- ☐ Submissive
- ☐ Snobbish
- ☐ Unconventional

To perform the quantification process, knowledge about which of the presented adjectives are negatively related to creativity and which are positively related is needed. The table below shows this information. The details of the quantification process can be found in Section 5.5.1.

Positive Adjectives (18)	**Negative Adjectives (12)**
Capable	Artificial
Clever	Cautious
Confident	Commonplace
Egotistical	Conservative
Humorous	Conventional
Individualistic	Dissatisfied
Informal	Suspicious
Insightful	Honest
Intelligent	Well-mannered
Wide interests	Narrow interests
Inventive	Sincere
Original	Submissive
Reflective	
Resourceful	
Self-confident	
Sexy	
Snobbish	
Unconventional	

IV
CREATIVE SELF-EFFICACY SURVEY

The creative self-efficacy survey used in the experiment outlined in Chapter 5 is based on the Creative Self-Efficacy (CSE) scale proposed by Tierney and Farmer (2002). The survey was administered online and presented to the participants as follows:

On a scale from 1 (strongly disagree) to 5 (strongly agree), indicate your agreement with each of the following statements.

	strongly disagree 1	2	3	4	strongly agree 5
I am good at coming up with new ideas	○	○	○	○	○
I have a lot of good ideas	○	○	○	○	○
I have a good imagination	○	○	○	○	○

The details of the quantification process can be found in Section 5.5.1.

V
CREATIVE POTENTIAL SURVEY

The creative potential survey used in the experiment outlined in Chapter 5 is based on the short version of the Runco Ideation Behavior Scale (RIBS-S) proposed by Runco et al. (2000). The survey was administered online and presented to the participants as follows:

Indicate how often each of the phrases below describes your thinking. Note that the focus is on your thinking, which might be different from your actual behavior. Also, note that you may need to approximate. Please indicate how you really think, not how you believe you should act. Remember, no names are used. Your responses are confidential.

Again, you may need to approximate. For each phrase, select the response option that is THE CLOSEST to being accurate. Here are the options:

0 = never
1 = approximately once a year
2 = approximately once or twice each month
3 = approximately once or twice each week
4 = just about every day, and sometimes more than once a day

		0	**1**	**2**	**3**	**4**
1	I have ideas for arranging or rearranging the furniture at home	○	○	○	○	○
2	I have ideas for making my work easier	○	○	○	○	○
3	I read something (written by someone else) and realize there are alternative perspectives	○	○	○	○	○
4	I have ideas about what I will be doing in the future	○	○	○	○	○
5	I consider alternative careers (or career changes)	○	○	○	○	○

0 = never
1 = approximately once a year
2 = approximately once or twice each month
3 = approximately once or twice each week
4 = just about every day, and sometimes more than once a day

		0	**1**	**2**	**3**	**4**
6	I have trouble sleeping at night, so many ideas keep showing themselves keep me awake	○	○	○	○	○
7	I make plans (e.g., going to a particular restaurant or movie), but something messes it up–yet it is easy for me to find something to do instead	○	○	○	○	○
8	I have ideas about a good plot for a movie or TV show	○	○	○	○	○
9	I have ideas about a new invention	○	○	○	○	○
10	I have ideas for stories or poems	○	○	○	○	○
11	I have an idea about a new route between home and school (or work)	○	○	○	○	○
12	I have ideas for a new business or product	○	○	○	○	○

0 = never
1 = approximately once a year
2 = approximately once or twice each month
3 = approximately once or twice each week
4 = just about every day, and sometimes more than once a day

		0	1	2	3	4
13	I see a cloud, shadow, or similar ambiguous figure and have SEVERAL ideas about what the shape or figure could be	○	○	○	○	○
14	I have ideas about what I will be doing 10 years from now	○	○	○	○	○
15	I have trouble staying with one topic when writing letters because I think of so many things to say	○	○	○	○	○
16	I often see people and think about alternative interpretations of their behavior	○	○	○	○	○
17	When reading books or stories I have ideas of better endings	○	○	○	○	○

0 = never
1 = approximately once a year
2 = approximately once or twice each month
3 = approximately once or twice each week
4 = just about every day, and sometimes more than once a day

		0	1	2	3	4
18	When reading the newspaper or a letter that someone wrote, I often have ideas for better wording	○	○	○	○	○
19	I hear songs and think of different or better lyrics	○	○	○	○	○

The details of the quantification process can be found in Section 5.5.1.

VI
CUES AND OBJECTS

This appendix lists the set of near and far cues and their associated objects used in the experiment outlined in Chapter 5. The list was adopted from Hartog et al. (2020). See Section 5.3.2 for information about how the list was adopted. The information in the first column, SN, and the last column, Practice? is for organization purposes and is not shown to the participants. An “x” in the last column indicates that the object and its associated cues are used in the practice part of the experiment and not the main part.

SN	Object	Near Cue	Far Cue	Practice?
	Brick	Construction Material	Paper Weight	x
1	Billiard Ball	Billiards	Doorknob	
2	Shoe	Clothing	Pot Plant	
3	Screwdriver	Screwing	Pry Bar	
4	Toilet Seat	Seating	Picture Frame	
5	Aluminum Foil	Cover Food	Hat	
6	Hanger	Hang Clothing	Unlock Car Door	
7	Helmet	Protect Head	Basket	
8	Pencil	Writing With	Stir Stick	
9	Pipe	Transfer Liquid	Weapon	
10	Cardboard Box	Storage	Play Fort	
11	Shoelace	Tie Shoe	Belt	
12	Band-aid	Cover Wound	Tape	
13	Rolling Pin	Cooking Tool	Muscle Massager	
14	Rubber Band	Hold Items Together	Slingshot	
15	Sock	Footwear	Sock Puppets	
16	Mirror	Reflection	Signal for Help	
17	Magnifying Glass	Magnify Image	Start Fire	
18	Sandpaper	Smooth Surface	Nail File	
19	Paint Brush	Painting	Broom	
20	Toothpick	Clean Teeth	Craft Item	
21	Mason Jar	Preserve Food	Light Bulb Cover	
22	Lipstick	Makeup	Writing Utensil	
23	School Bus	Transportation	Mobile Home	
24	Water	Drink	Generate Electricity	
25	Safety Pin	Fastener	Earring	
26	Chewing Gum	Breath Freshener	Putty	
27	Scissors	Package Opener	Pizza Cutter	
28	Artificial Turf	Football Turf	Bathmat	
29	Coca-Cola	Beverage	Toilet Cleaner	
30	CD-ROM	Disk	Coaster	
31	Scuba Flippers	Swim Aid	Fan Blades	
32	Coconut	Food	Bocce Ball	
33	Ice Skate	Ice Skating	Cleaver	

SN	Object	Near Cue	Far Cue	Practice?
34	Credit Card	Means of Payment	Butter Knife	
35	Nail File	Manicure	Carrot Peeler	
36	Paddle	Rowing	Pizza Oven Slider	
37	Nylon Stocking	Women's Clothing	Filter	
38	Toilet Paper	Hygiene Product	Padding	
39	Tennis Racket	Sports Equipment	Colander	
40	Knitting Needles	Knitting	Chopsticks	
41	Record Player	Music Player	Pottery Wheel	
42	Trampoline	Gymnastic Apparatus	Bed	
43	Ironing Board	Ironing Pad	Shelf	
44	Fork	Eat	Comb	
45	Thermos	Coffee Warmer	Vase	
46	Matches	Lighter	Cheese Skewers	
47	Door	Passage	Ping Pong Table	
48	Surfboard	Surfing	Ironing Board	
49	Watering Can	Gardening Equipment	Wine Decanter	
50	Spatula	Kitchen Utensil	Putty Knife	
51	Ruler	Measurement	Curtain Rod	
52	Bottle Cap	Bottle Topper	Cookie Cutter	
53	Cotton Ball	Make-up Removal	Christmas Decorations	
54	Canoe	Boat	Bathtub	
55	Spoon	Cutlery	Trowel	
56	Antlers	Wall Decorations	Coat Hook	

VII
TASK ENGAGEMENT SURVEY

The task engagement survey was inspired by items from the Immersive Experience Questionnaire (IEQ) developed by Jennett et al. (2008) and the Game Engagement Questionnaire (GEQ) developed by Brockmyer et al. (2009). The survey was administered electronically on a computer directly after performing the main task in the lab. The questions were presented individually to the participants as follows:

How engaging the experiment was to you?

	1	2	3	4	5	
boring	○	○	○	○	○	interesting

How likely are you to recommend participating in this study to your friends?

	1	2	3	4	5	
highly unlikely	○	○	○	○	○	highly likely

How likely are you to participate in similar studies in the future?

	1	2	3	4	5	
highly unlikely	○	○	○	○	○	highly likely

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