INVESTIGATING THE ROLE OF INCUBATION IN DESIGN CREATIVITY FROM A NEUROSCIENTIFIC PERSPECTIVE

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY
IN
INDUSTRIAL DESIGN

JANUARY 2025

Approval of the thesis:

INVESTIGATING THE ROLE OF INCUBATION IN DESIGN CREATIVITY FROM A NEUROSCIENTIFIC PERSPECTIVE

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ABSTRACT

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January 2025, 283 pages

Creativity in design is a multifaceted phenomenon shaped by the relationship between person, process, and product. This thesis investigates the role of the incubation period in design creativity, a critical yet understudied stage of the creative process. Drawing on the four-stage model of Wallas, the study examines the effect of incubation on creative performance and its relationship with creative potential. Employing a concurrent mixed methods approach, the study integrates qualitative and quantitative analyses to explore the cognitive mechanisms underpinning incubation, combining electroencephalography (EEG), self-report measures of creative potential, and evaluations of creative outcomes. Seventeen industrial design undergraduates participated in a laboratory experiment designed to investigate three key aspects: (1) the impact of incubation on creative performance, (2) the connection between creative potential and the cognitive mechanisms underlying incubation, and (3) the link between creative potential and creative performance. The findings indicate that upper alpha suppression in the frontal regions predicts cognitive effort and convergent thinking during incubation, suggesting a controlled search within semantic memory. Notably, while the intensity of this suppression negatively correlates with the novelty of design solutions, the study found no evidence that variety and quantity benefit from an incubation period. A significant improvement from control to incubation conditions in novelty scores in one of the two design task groups suggests that the observed increase may stem from incubation effects rather than task differences alone. Overall, the results emphasize the value of breaks in stimulating associative processes that aid novelty generation.

Keywords: Incubation, Design Creativity, Design Cognition, Semantic Memory, Neuroimaging

ÖZ

TASARIM YARATICILIĞINDA KULUÇKA EVRESİNİN ROLÜNÜN NÖROBİLİM PERSPEKTİFİNDEN İNCELENMESİ

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Tasarımda yaratıcılık, kişi, süreç ve ürün arasındaki ilişkiyle şekillenen çok yönlü bir olgudur. Bu tez, yaratıcı sürecin kritik ancak yeterince çalışılmamış bir aşaması olan kuluçka evresinin tasarım yaratıcılığındaki rolünü araştırmaktadır. Wallas tarafından önerilen dört aşamalı modeli temel alan çalışma, kuluçka evresinin yaratıcı performans üzerindeki etkisini ve yaratıcı potansiyel ile ilişkisini incelemektedir. Eş zamanlı bir karma yöntem yaklaşımı kullanan çalışma, elektroensefalografi (EEG), yaratıcı potansiyelin öz bildirim ölçümleri ve yaratıcı sonuçların değerlendirmelerini birleştirerek, kuluçka evresinin altında yatan bilişsel mekanizmaları keşfetmek için nitel ve nicel analizleri entegre etmektedir. On yedi endüstriyel tasarım lisans öğrencisi, üç temel soruyu araştırmak üzere tasarlanmış bir laboratuvar deneyine katılmıştır: (1) kuluçka evresinin yaratıcı performans üzerindeki etkisi, (2) yaratıcı potansiyel ile kuluçka evresinin altında yatan bilişsel mekanizmalar arasındaki bağlantı ve (3) yaratıcı potansiyel ile yaratıcı performans arasındaki bağlantı. Bulgular, ön bölgelerdeki üst alfa baskılanmasının kuluçka evresi sırasında bilişsel çabayı ve yakınsak düşünmeyi öngördüğünü ve semantik bellek içinde kontrollü bir arama yapıldığını göstermektedir. Özellikle, bu bastırmanın yoğunluğu tasarım çözümlerinin yeniliği ile negatif korelasyon gösterirken, çalışmada çeşitlilik ve fikir sayısının kuluçka evresinden fayda sağladığına dair bir kanıt bulunamamıştır. Bir tasarım görevi grubunda yenilik puanlarındaki önemli bir iyileşme, gözlemlenen artışın yalnızca görev farklılıklarından ziyade kuluçka evresinin etkilerinden kaynaklanabileceğini düşündürmektedir. Bulgular, yenilik üretimine yardımcı olan çağrışımsal süreçlerin uyarılmasında molaların değerini vurgulamaktadır.

Anahtar Kelimeler: Kuluçka Evresi, Tasarımda Yaratıcılık, Tasarım Bilişi, Semantik Bellek, Nörogörüntüleme

to my beloved companions, Memphis and Peyote…

ACKNOWLEDGMENTS

I would like to especially express my gratitude to my thesis supervisor, Assoc. Prof. Dr. Naz A.G.Z. Börekçi, for her invaluable guidance, open-mindedness in supporting this multidisciplinary study, and encouragement throughout my thesis. Her mentorship truly shaped my research and academic growth.

I am deeply thankful to my thesis co-supervisor, Assoc. Prof. Dr. Tolga Esat Özkurt, for his support in this explorative study and for the research environment he provided. His thoughts on the philosophy of science and life, as well as his criticism, deeply affected my perspective and scientific journey.

I especially want to appreciate the contribution of Igor Mapelli, and being a company at the lab during hard times. I thank him for his endless support of the technical problems and theoretical aspects without hesitation.

I would like to thank Hüseyin Matur, a curious scientist candidate, for his hands-on assistance during the experiments at the lab and his positive attitude despite any technical challenges.

I am deeply grateful and feel so lucky to have my family and friends who were with me along this journey and have always encouraged me. My sincere appreciation to Pınar Yurt, who is a great scientist, for her forever support in every aspect of my thesis and for her emotional support as my lovely sister.

My heartfelt thanks go to my partner Virani Başkurt, not just for his continued support but also for his contribution to the development of the code for the computational sketch analysis.

The experiment phase of the study is funded by the Scientific and Technological Research Council of Turkey under grant number TUBİTAK 1002-B.

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ABBREVIATIONS

EEG: Electroencephalography

PFC: Prefontal cortex

DMN: Default Mode Network

CTMS: Creative Trait Motivation Scale

CPAC: Cognitive Processes Associated with Creativity

PTB: Psychtoolbox

EII Theory: Explicit Implicit Interaction Theory

CHAPTER 1

INTRODUCTION

Creativity in design can be defined as the process where exploration and generation take place iteratively and end up with an output that is useful and novel. One of the earliest models of the creative process, Wallas' four-stage model, places incubation as an essential step for creative productions. In product design, incubation is seen as one of the several sources to promote ideas and one of the ways to prevent fixation after the problem space is explored and new ideas are generated. Based on the fact that deepening our knowledge of the effect of incubation will enable us to adapt it more efficiently and consciously into the design process, this study focuses on the effect of incubation on creative performance and its relationship with creative potential. The study will make use of concurrent mixed methods to explore the phenomenon. It will benefit from neuroimaging tools to open a window into design cognition. Its quantitative nature will contribute to theory construction in design research.

1.1 Problem Statement

Creativity is a multifaceted phenomenon that requires a critical and extensive investigation. Rhodes' (1961) classification into four aspects, which are person, process, press (environment), and products (4Ps), is still widely cited (e.g., Runco, 2011; Kaufman, Plucker and Baer, 2008; Tang et al., 2017). Runco and Kim (2011) further attempt to include persuasion as the fifth aspect of which social judgment and historical impact are argued. In design research, although many studies focus on creativity in products and processes, other dimensions of creativity can be remarked on since the design process is a complex problem-solving process. Thus, a more holistic approach is needed to study design creativity in order not to rule out innate qualities.

This study comprehensively approaches creativity by covering the person's creativity (creative potential), process, and product (creative performance). This way, both approaching creativity without reducing its qualities and understanding the relationships between the creative person, process, and product in the design process will be attainable.

Design practice is an iterative process that iterates between divergent and convergent thinking to address complex problems. It begins with exploring the problem space and gathering essential knowledge, followed by generating potential solutions and refining them toward an outcome. A break can be introduced between problem exploration and ideation, during which the problem is temporarily set aside—a stage known as incubation. Numerous hypotheses highlight the positive effects of incubation on problem-solving (Sio and Ormerod, 2009), proposing various mechanisms to explain the phenomenon.

Incubation is recognized as an effective tool for stimulating ideas in creative design processes (Kirjavainen and Höltta, 2020), particularly for overcoming fixation (Shah et al., 2003; Kohn and Smith, 2009; Tsenn et al., 2014; Sio, Kotovsky, and Cagan, 2017). However, compared to other ideation mechanisms of the creative process, incubation has been less studied in the context of design.

There is a need to investigate incubation within the design domain to understand its mechanisms and effectively integrate it into design practices. Since incubation effects are significantly influenced by problem types and individual traits (Sio and Ormerod, 2009), studying it within the context of design is crucial to better comprehend and utilize its potential benefits.

While qualitative methods have been instrumental in uncovering the cognitive functions behind design practice (Ger and Milovanovic, 2020), there remains a need for empirical investigations to deepen our scientific understanding and enhance practical design guidelines. The extensive knowledge we have about design cognition owes much to qualitative studies, but complementing these with quantitative approaches can provide additional insights, particularly in the growing field of design research. Developing a robust, field-specific framework of techniques and knowledge requires integrating diverse methodologies (Cash et al., 2016). Cognitive neuroscience, with its advanced tools and methodologies, offers a unique opportunity to explore the specialized roles of cognitive mechanisms, adding depth to our understanding of design cognition and influencing design theory (Alexiou et al., 2009). This study aims to adapt these tools to design cognition research, not to replace qualitative methods, but to address their limitations and provide a more comprehensive perspective.

Design cognition research is an evolving field, often criticized for prioritizing descriptive studies over theoretical advancements, with theory development in the field stagnating for over a decade (Hay, Cash, and McKilligan, 2020; Cash, 2020). This study aims to tackle these challenges by using a quantitative approach to examine hypotheses on creative cognition, thereby advancing the development of more theoretical frameworks in the field.

1.2 Aim of the Study

The aim of this study is to understand the role of incubation in design creativity. It adapts concurrent mixed methods and conducts lab experiments with 17 participants who are in their third and fourth year in an industrial design undergraduate program. It first makes an inquiry into creative potential by conducting creative self-report scales. Then, it investigates the mechanisms underlying the incubation period during a design problem-solving process employing a neuroimaging technique. The unfilled incubation period helps to reveal spontaneous brain activity related to cognitive processes enabling the incubation effect. Afterward, it investigates the impact of the incubation period on creative performance by evaluating the design outcomes.

The objectives of this study are to clarify the relationships between
(1) incubation period and creative performance,
(2) creative potential of participants and creative process
(3) creative process and creative performance.

The goal is to make a theoretical contribution to research on design cognition by revealing the relationship between these variables and to inform design practice by reporting the effect of incubation on creative performance in the design process. In line with this, the study hopes to contribute to the neuroscience of creativity in terms of providing information on a particular cognitive function and extending the methodologies of cognitive neuroscience where ill-defined problems are investigated and greater ecological validity is aimed in the design domain.

1.3 Research Questions

This thesis hopes to answer the following research questions.

a. How does an incubation period affect creative performance?
   - Which metrics differ at the end products between incubation and non-incubation conditions?
b. How do cognitive functions differ between resting state and incubation?
   - How is the brain oscillatory activity modulated during the incubation period?
   - How is an incubation period affected by creative potential?

To answer these questions, a research framework based on a multi-strategy (mixed-methods) design comprising three stages is constructed: pre-experiment self-reports, a multi-phase experiment, and post-experiment product evaluation, all designed to complement one another.

1.4 Research Approach

Empirical design research consists of three approaches: laboratory, practice, and intermediary (also known as quasi-experiment) (Cash, Hicks, and Culley, 2013). Whereas the first refers to studies conducted in different environments typically using students, the second makes use of ethnographic or embedded study employing observations with practitioners, and the third is the blend of laboratory and practice, where experiments vary slightly from real practice and generally use practitioners (Cash, Hicks and Culley, 2013). This study is an example of a laboratory study, where students are used as sampling, casual relationships are established, and variables are predefined and controlled.

Experiment designs also differ by the level of control experimenters have over the conditions. This study is positioned as a true experiment because it uses randomization where each participant goes under two conditions, and the setup is capable of demonstrating cause and effect (Cash, Stankovic, and Storga, 2016).

Cognition refers to various higher mental processes such as perceiving, thinking, and planning (Ward, 2015). The study of design cognition starts with the aim of observing the nature of the design process as opposed to proposing prescriptive methods (Goldschmidt, 2017). Gero and Kan (2016) discuss research into design cognition studies under five general categories based on the methods they apply: (1) questionnaires and interviews, (2) input-output experiments, (3) anthropological studies, (4) protocol studies, and (5) cognitive neuroscience studies. A more recent study by Gero and Milovanovic (2020) investigates the studies in this scope by grouping design cognition, design physiology, and design neurocognition under design thinking. While the first one forms the highest percentage of this literature, the studies within this group apply conventional analysis of processes and products (Gero and Milovanovic, 2020). The second group indicates the studies using physiological measurement tools such as eye-tracking and emotion-tracking to uncover affective and mental processes of design thinking, and the last group applies methods from cognitive neuroscience such as electroencephalography

(EEG) and functional magnetic resonance imaging (fMRI) to unfold cognitive functions behind design thinking (Gero and Milovanovic, 2020). This study agrees with the fact that qualitative methods such as protocol studies are limited in capturing non-verbal, imperceptible, and embedded designerly activities (Cross, 2007).

Cognitive neuroscience is a field of study that focuses on a neural basis that underlies cognition. It employs various tools using different mechanisms to track brain activity and interpret cognitive functions. Recording methods and behavioral tests are used to understand the brain-based mechanism of a particular cognitive function by tracking the brain areas activated to support that cognitive function (Alexiou, Zamenopoulos, Johnson, and Gilbert, 2009). Recently, tools of cognitive neuroscience have been adapted into design research focusing on problem-solving (Goel and Grafman, 2000; Goel, 2010; Goel, 2014; Alexiou and Gilbert, 2009; Vieira et al., 2019), expertise (Liang and Liu, 2007; Göker, 1997), idea generation (Benedek, 2018; Nguyen and Zeng, 2014; Shealy et al., 2020; Vieira et al., 2019), and inspiration (Goucher-Lambert et al., 2019).

For more than a half-century, creativity has been studied within various areas by applying different tasks to evaluate. Studying neural correlates of creative cognition is a relatively emerging area. The creative cognition approach aims to understand how creative ideas are being produced (Beaty et al., 2016). The biggest challenge in this area is that creativity is an extensive and multidimensional phenomenon that is hard to implement in any study. It requires a deliberate research design not to reduce its qualities while studying it nor to generalize the outcomes of studies incorrectly.

As an emerging field and term, design neurocognition covers studies using tools of cognitive neuroscience to investigate design cognition (Balters et al., 2022; Ohashi et al., 2022, Gero and Milovanovic, 2020). Cognitive neuroscience offers several methods, some of which are EEG, fMRI, fNIRS, and MEG. While EEG gathers data on the electrical activity of the brain from the scalp, fMRI and fNIRS record the changes in blood oxygen level with different principles, and MEG detects changes in magnetic fields produced by the electrical activity of the brain (Seitamaa-Hakkarainenet al., 2014). Each of these tools has different advantages and disadvantages. Within this study, we chose to use EEG because of its noninvasiveness, high temporal resolution, and availability in a lab at the university where this research is conducted.

The challenges that arise from the combination of cognitive neuroscience and design cognition research are to adapt the methods of the former into the latter with a considerable level of losing ecological validity and to arrange the duration of tasks to be measurable quantitatively but also be interpretable qualitatively. Although different protocols are employed in design and neuroscience experiments traditionally, recent studies offer new ways of combining these methodologies. This study aims to combine these methodologies by decreasing ecological validity and task durations, as well as enhancing interaction for response types.

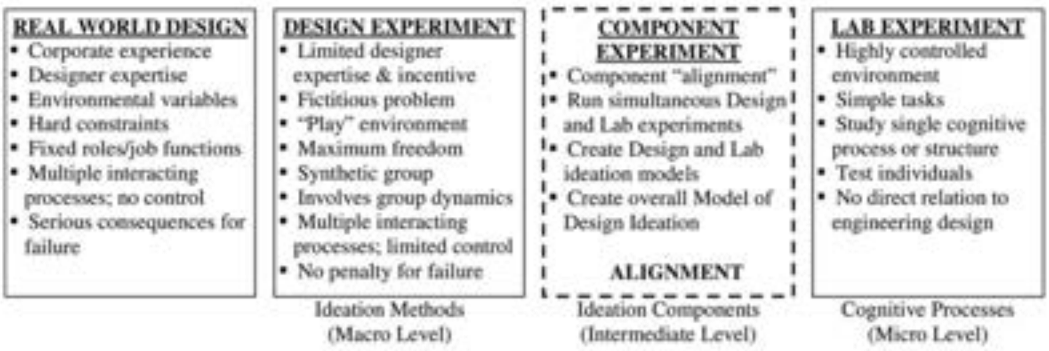

Figure 1.1 Levels of ecological validity (Taken from Hernandez, Shah, and Smith, 2010, p.385)

The table constructed by Hernandez, Shah, and Smith (2010) shows the levels of ecological validity and characteristics of these levels in empirical design research. This study can be positioned under the micro level, that is, a lab experiment.

The role of incubation in design creativity is addressed in this study by employing a concurrent mixed methods design. This is a type of design in which qualitative and quantitative data are collected in parallel, analyzed separately, and then merged. During the experimental phase, participants are assigned two design tasks while electroencephalography (EEG) data is recorded to investigate the cognitive mechanisms occurring during the incubation period and their impact on creative performance. Prior to the experimental phase, self-reports have been adapted to investigate the person's creativity (creative potential). Collecting both qualitative and quantitative data allows for a comprehensive exploration of the incubation phenomenon, capturing the multidimensional nature of creativity while ensuring that the methods validate each other.

1.5 Contribution to the Field

The findings of this research will contribute to two key fields: design research and cognitive science. In the context of design research, the study aims to advance both design theory and practice. Theoretical contributions are made by uncovering the mechanisms of incubation and its impact on design creativity. This understanding is expected to provide valuable insights into how the incubation period can be effectively applied in the design process, bridging the gap between theory and practice.

On the other hand, this study is expected to contribute to the neuroscience of creativity by providing a deeper insight into creativity in the context of design. Besides, it is hoped to provide an example of a different approach to the methodology of neuroscience experiments, in which the problem type is ill-defined and ecological validity is increased.

Given that studies employing lab experiments to study design cognition are relatively new, this study is carefully structured, and the thorough documentation of research design and data collection process is intended to serve as a valuable resource for emerging scholars, offering insights and guidance for designing their studies by learning from the challenges and experiences detailed herein.

1.6 Structure of the Thesis

The thesis is organized into four chapters. The first chapter, Introduction, gives an overview of the research problem, research aim, research questions, research approach, contribution to the field, and the general structure and scope of the thesis.

Following the introduction, the second chapter, Literature Review, explores the existing body of knowledge related to creativity in an extensive scope and then narrows down to creativity in design. Incubation is addressed in relation to design. This chapter critically assesses previous studies, identifying gaps in the literature and positioning the current research within the broader context. Eventually, the theoretical framework is proposed based on the literature, in which the research philosophy and theoretical perspectives that inform this study are discussed.

The third chapter, Methodology, presents the research framework of the thesis. It details the research design, methods, and procedures used for data collection and analysis. It includes a thorough description of the sampling, the instruments used for data collection, the techniques employed to analyze the data, and mentions the challenges that the researcher encountered within the data collection process. Following this, the findings are reported, with an in-depth examination of the data collected, highlighting the results of self-reports, sketch evaluation, oscillatory analysis, and correlational analysis. End of this chapter, a preliminary discussion has been made to close out it with a holistic perspective.

In the final chapter, Conclusion, the results are discussed, revisiting the research questions. Finally, contributions, limitations, and future research possibilities are discussed.

CHAPTER 2

LITERATURE REVIEW

This chapter presents a review of relevant topics in creativity and incubation. The chapter starts with definitions and theories of creativity, from a broad perspective without specifying the domain. It is followed by the cognition of creativity and evaluation of creative processes, products, and persons. Then, the place of creativity in design is discussed. After examining creativity in the design domain, the chapter gives a place to theories of incubation and its relationship with design. At the end of it, the theoretical framework of the thesis is addressed.

2.1 Creativity

The scope of creativity is vast and varied. It is possible for it to find a place in any research area. Within the scope of this thesis, it is aimed to cover fundamental approaches and theories from creativity research to form a base for constructing their relationship with design.

2.1.1 Defining Creativity

There are dozens of definitions of creativity in the literature that cover many distinct fields. While it is possible to notice general trends in research when inquiring into the literature historically, it is still possible to discern controversy between the perspectives that will be mentioned further. Nevertheless, in a basic sense, it is possible to mention creativity when an artificial product, service, invention, or idea appears to be both novel and useful (Stein, 1953; Boden, 2003;

Plucker, Beghetto, and Dow, 2004; Runco, 2014; Bromley and Kaufman, 2015). Yet, many factors, including the field of study, assessment methods, and theoretical perspectives, affect how to approach the term creativity.

Table 2.1 Creativity definitions of different researchers

Stein, 1953	A process that results in a novel work that will be considered useful at a point in time.
Mednick, 1962 (as cited in Eysenck, 1994)	The forming of associative elements into new combinations which either meet requirements or in some way useful
Veron, 1989 (as cited in Eysenck, 1994)	Creativity denotes a person's capacity to produce new or original ideas, insights, inventions, or artistic products, which experts accept as being of scientific, aesthetic, social, or technical value.
Boden, 2003	Creativity is the ability to develop ideas or artifacts that are new, surprising, and valuable.
Plucker, 2004	Creativity is the interaction among aptitude, process, and the environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context.
Runco, 2014	Originality is vital but must be balanced with fit and appropriateness.
Bromley, 2015	Creativity must represent something different, new, or innovative. Second, it also must be useful, relevant, and appropriate to the task.

Before the 1950s, it was common to approach creativity as a mysterious and indescribable phenomenon. The scientific study of creativity only begins around the 1950s. Nevertheless, as Runco and Jaeger (2012) suggested, the duality in the definitions of creativity was already accepted during the 1960s, which indicates that it should be rooted back before this date. It is believed that the source of the creativity definition with two components goes back to the 1900s, such as Royce's (1898, as cited in Runco and Jaeger, 2012) usage of the phrase "valuable inventiveness". Besides, even though the studies on creativity accelerated by the 1950s, approaching creativity in the frame of a specific domain rooted back to the 1930s (Runco and Jaeger, 2012). Early studies on creativity were conducted by scholars who investigated genius and intelligence; as a matter of course, creativity was delved from the account of intelligence (Kaufman and Glaveanu, 2019). Yet, since genius has been related to mental illnesses, thanks to the Latin roots of the word, which refers to genius and inspiration as the same thing, creativity was also seen as an individualistic trait (Kaufman and Glaveanu, 2019; Eysenk, 1995). During the 1950s and 1960s, intelligence was still preserving its dominance, and creativity was seen as the same thing or a by-product of intelligence (Runco, 2014; Sawyer, 2012). The presidential speech in 1949 of APA president Guildford was a breaking point in the research area of creativity (Guilford, 1950). It was also the era of the humanist movement in which self-realization rose (Alencar et al., 2014). For creativity, research leads to addressing and studying personal creativity, *aka* p-creativity and little-c. It was not until the rise of cognitive psychology in the 1970s and 1980s that creativity was studied within the societal context and universal commons in terms of cognition. As Sawyer (2012) noted:

> "(...) rather than explaining these differences (the level of creativity in persons) in terms of personality traits, cognitive psychologists believe that they can best be understood in terms of variations in the use of specific, identifiable processes -such as the flexibility of stored cognitive structures, the capacity of memory and attention systems, and other basic cognitive principles (Sawyer, 2012, p. 87)."

Csikszentmihalyi (2007) finds the usage of 'creativity' to be a problematic term in the sense of wideness in the term. Because it covers many meanings, it also confuses. He distinguishes at least three different usages in general. The first one refers to people who come with unusual thoughts in a conversation. He prefers to refer to them as brilliant rather than creative. The second focuses on individuals who perceive and experience the world in unique and novel ways, characterized by fresh insights and independent discoveries that may go unnoticed by others, as highlighted by Csikszentmihalyi (2007). The third usage of the term refers to people who changed the culture profoundly, like Einstein or Picasso. This is the type of creativity called 'creativity with capital C'. Csikszentmihalyi (2007) defines the person with capital C whose productions change or establish a new domain. This usage is similar to the definition of Boden's (2003) H-creativity, which indicates the rise of an idea that is the first time in the history of humans. Boden highlights that it is a particular type of P-creativity, which points out the novel and practical idea of a person without considering the occurrence of that particular idea in other minds before.

To indicate who/what/how much a person or a product is creative, according to Csikszentmihalyi (2007), the concept of creativity needs to be considered on three levels. According to his Systems Theory, creativity is only possible with the interaction between field, domain, and the person. The field represents the social aspect of the environment, and the domain represents the cultural or symbolic aspect (Csikszentmihalyi, 2014). Therefore, the creativity of a person should be accepted by the field in the domain in which one expresses oneself. The point of time it is considered creative might exceed one's lifespan (Stein, 1953).

2.1.2 Creative Process

When we look at the process where creativity arises, it is possible to come across different perspectives, some of which approach creativity as problem-solving, and some approach problem-solving as a type of creativity (Sawyer, 2012; Runco, 2014). Runco (2014) suggests that not all problems require creative thinking, and creativity is not always the only way to generate a solution for a problem since problems differ in terms of the thinking patterns required to tackle them. de Bono (1969) defines three types of problems: (1) problems that require handling the available information or collecting new information, (2) situations of no problem, where it is not needed to develop a better condition, and the current state is accepted, and (3) problems that are solved with restructuring the available information. Similarly, Csikszentmihalyi and Sawyer (2014) distinguish the statement of the problem at the beginning of the creative process. If the problem is predefined, what they refer to is *presented problem-solving*; what remains is to find a solution to it. If the problem is undefined, that is *discovered problem-finding process*, the process tends to be longer, and the definition of the problem might extend until the first insight. They point out that revolutionary developments belong to this second category (Csikszentmihalyi and Sawyer, 2014).

Studying problem-solving can contribute to our comprehension of the creative process by which well-defined and ill-defined problems are recognized (Runco, 2014). Goel (2014) advocates that real-world problems are ill-defined and suggests that while the problem area is ill-structured initially, it becomes clearer and well-structured while progressing step by step. Whereas the answers to well-defined problems can be right or wrong, those to ill-defined problems can be worse or better (Goel, 2010). He defines an ill-structured problem-solving process with the following four steps: problem scoping, preliminary solutions, refinement, and detailing, and explains as follows:

> "Each phase differs with respect to the type of information dealt with, the degree of commitment to generated ideas, the level of detail attended to, the number and types of transformations engaged in, the mental representations needed to support the different types of information and transformations, and the corresponding computational mechanism. (Goel, 2014, p. 616)."

The basic model of the creative process includes two phases: divergent thinking or ideation and convergent thinking, in which combinations of certain ideas are brought to life. Many contemporary models rely on Wallas' (1926, as cited in Tang et al., 2017) iterative four-stage creative process model that follows preparation, incubation, illumination, and verification. The preparation stage contains the conscious inquiry into knowledge while a preliminary analysis of the problem takes place. Then, even though there is no conscious attempt to solve the problem during incubation, the mind partially processes the knowledge gained during the first step. After that, ideas start to shape a form during the illumination phase. This is the phase in which the sudden emergence of ideas can occur and is also known as the 'a-ha moment,' 'Eureka,' and 'the moment of insight' (Sawyer, 2012). Finally, during the verification phase, ideas are evaluated and refined (Tang et al., 2017). Heile and Sun (2010) analyze Wallas' four-stage creativity model based on their explicit-implicit interaction (EII) theory. Reed (2017) explains the theory as follows:

> "The theory postulates that the initial preparation phase is predominately rule-based processing as people respond to verbal instructions, from representation of problem, and establish goals. In contrast, the second incubation state is predominately implicit processing in which people may not consciously think about the problem. The third stage, insight, occurs when internal confidence level crosses a threshold that makes the output available for verbal report. The final verification stage, like the initial stage, requires primarily explicit processing to evaluate the potential of the discovered solution" (Reed, 2017, p .243).

When the model transforms into having many more steps, it makes clear the outline of the process. Sawyer (2012) identifies the process with eight stages: (1) Finding and formulating the problem, (2) acquiring relevant knowledge about the problem, (3) gathering a wide range of related information that has potential, (4) period of leave for incubation, (5) generating ideas, (6) combining ideas in an unpredicted way, (7) selecting the best idea that fits the criteria, and (8) externalizing the idea via different representations. On the other hand, Cropley (2006) examines the creative process by fragmenting the process into seven phases, which are (1) information, (2) preparation, (3) incubation, (4) illumination, (5) verification, (6) communication, and (7) validation. Table 2.1 represents the phases of the creative process according to this model.

It can be seen that the information processing (whether divergent or convergent) differs from phase to phase. As also seen from the actions corresponding to each phase, various thinking patterns are required to tackle the problem.

A recent framework for the creative process suggested by Benedek et al. (2023) also approaches the process formed with four steps, as in the pioneering ones. The framework called MemiC consists of four phases: memory search, candidate idea construction, novelty evaluation, and effectiveness evaluation. Although it has four steps, the process has an iterative nature.

Table 2.1 Creative process phases, related actions, and traits (Cropley, 2006, p. 402)

Phase	Action	Result	Necessary Process
Information	Perceiving Learning Remembering	Initial activity General knowledge Special knowledge	Convergent thinking
Preparation	Identifying problem Setting goals	Focused special knowledge Rich supply of cognitive elements	Convergent Thinking
Incubation	Making associations Bisociating Building networks	Combinations of cognitive elements	Divergent thinking
Illumination	Making a promising new configuration	Novel configuration	Divergent thinking
Verification	Checking relevance and effectiveness of the novel configuration	Appropriate solution displaying relevance and effectiveness	Convergent thinking plus divergent thinking
Communication	Acting on feedback	Effective presentation to others	Convergent thinking plus divergent thinking
Validation	Achieving closure	Product acclaimed by relevant judges	Convergent thinking

2.1.3 Creative Cognition

It is crucial to understand conceptual processes and cognitive operations of creativity to understand how it occurs and how to study it. Some of the pioneer models of creative cognition are investigated here to provide an essential background for the study.

BVSR Model

The blind variation and selective retention (BVSR) model approaches creative cognition within an evolutionary framework (Campbell, 1960; Jung et al., 2013; Simonton, 2010). The model still preserves its validity and is supported by new studies. It is based on three aspects of the evolutionary theory of Darwin: a) blind variation/generation of solutions, (b) evaluation/selection of a solution, and (c) retention of the chosen solution (Helie and Sun, 2010). According to this model, while blind variation generates originality, selective retention determines the appropriateness of an idea, just as divergence and convergence in the creative process. Although there was not enough evidence to support unconscious processing at that time, blind variation corresponds to the implicit processing part of the creative process. When ideas reach to maturity and provide a solution to the problem, insight occurs and ideas that are fit are retained while others that are not fit are not retained.

Threshold Theory

The Threshold Theory correlates creative production with intelligence. It proposes that a certain level of intelligence is required to grant creativity. The theory suggests that there is a relationship between creativity and intelligence, as can be seen in Figure 2.1. If the level of intelligence remains under the threshold, a person cannot even think for themselves to exhibit a creative product. When the threshold is crossed, it is not promised to manifest creativity, but the possibility arises (Runco, 2014).

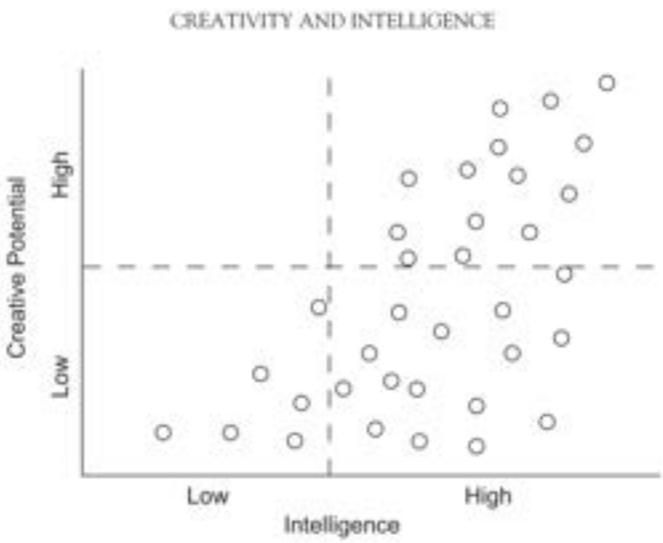

Figure 2.1 Scatterplot representing the relationship between intelligence and creative potential (Runco, 2014, p. 7)

Investment Theory

The Investment Theory constructs an analogy between investment, which profits from buying something low and selling high, and creative performance as well as the level of investors, which can be large or small scale, and the level of creativity, which indicates high and low creativity (Sternberg and Lubart, 1991). According to Sternberg and Lubart (1991), six sources can be found to contribute to the generation of creative ideas, which are intelligence processes, knowledge, intellectual styles, personality, motivation, and environmental context. Creativity arises from the confluence of these six sources, which can also be seen as incomes, and transformed into creative performances by using them effectively.

Geneplore Model

The Geneplore Model, which is one of the promising models, considers generative and exploratory processes of cognition and tries to explain cognitive processes related to creativity (Finke, Ward, and Smith, 1992). According to the model, mental representations or preinventive structures are constructed during the generative phase and then utilized for exploration of these properties in a meaningful way for purposes of creativity (Finke, Ward, and Smith, 1992). The process has an iterative manner in which the generation and interpretation occur in cycles. In the generative phase, mental representations are created. It is also called preinventive structures. Then, these representations are interpreted in various ways. Product constraints can be involved in one of these phases.

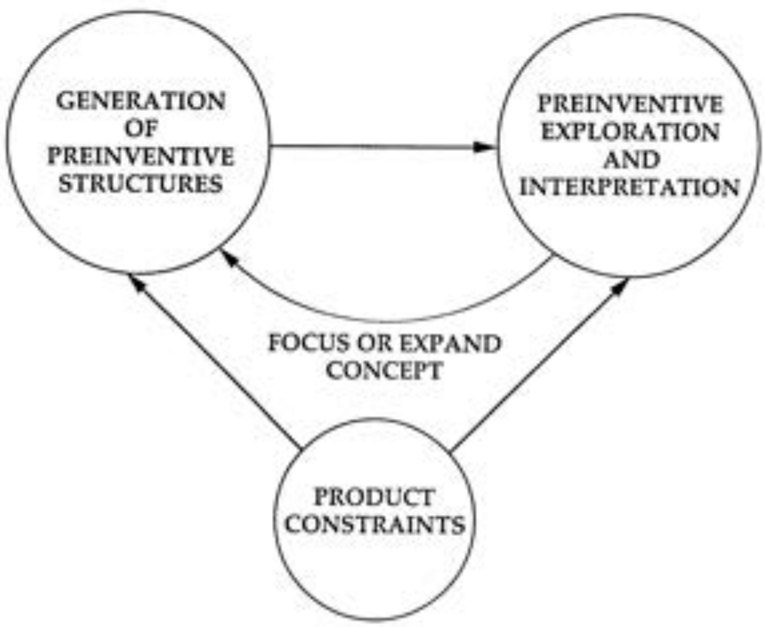

Figure 2.2 Geneplore Model (Finke, 1996, p.388)

The model has an important place in exploring the cognitive processes behind creativity.

Associative Theory

The Associative Theory is proposed by Mednick (1962) and tries to indicate the associations between generated ideas and their semantic distance (Runco, 2014). Mednick proposes that creative ideas come from semantically distant combinations, and creative people are better at relating those remote ideas to form a new one. He further demonstrates that it can be measured by experimental methods and proposes the Remote Associates Test (RAT) (Guo, Ge, and Pang, 2019).

A recent review conducted by Beaty and Kennett (2023) approaches associative theory in light of the recent advances in computational modeling and cognitive neuroscience. The evidence shows that associative thinking makes a contribution to domain-specific creative performance. It is also demonstrated that as the individual appears to be more creative, better navigation in semantic memory becomes possible, meaning that more distant associations can be connected.

The MemiC Framework

A recent framework proposed by Benedek et al. (2023) explores the role of memory in creative generations. The model goes in line with the two-phase models of the creative process, suggesting that generation and evaluation take place. Further, the generation phase is formed with two stages: relevant information is searched during the search phase and then the generation of ideas takes place. The evaluation phase also contains two stages: the ideas generated during the first phase are evaluated in this phase considering their novelty and effectiveness. During the generative phase, the problem solver conducts a search in the long-term memory and retrieves the relevant ones. Then, if the ideas do not meet the requirement of novelty and effectiveness, the solver returns to the generative phase until the criteria are met.

Explicit Implicit Interaction (EII) Theory

The theory explains creative cognition as the interaction between implicit and explicit processes. It begins with decomposition based on Wallas' (1926) creative process model. Following this, the five basic principles of the interaction between explicit and implicit processes are proposed (Table 2.2).

The first principle advocates that while explicit knowledge is more accessible and symbolic and employs rule-based reasoning, implicit knowledge is ambiguous, difficult to access and communicate, and employs associative processing. The second principle reveals that these two processes coexist in most tasks simultaneously. The third principle says that explicit and implicit knowledge often overlap, in which the implicit knowledge can become explicit through bottom-up learning, and explicit knowledge can become implicit after practice. The fourth principle suggests that the interaction between explicit and implicit knowledge may result in better performance, although they involve different types of processing and representations. The fifth principle advocates that the processing of implicit and explicit knowledge is often iterative, meaning that in case a clear result cannot be reached, another loop of processing rounds might take place, which uses the integrated outcome from the previous processing loop.

Table 2.2 Basic principles of EII Theory by Helie and Sun (2010, p.997)

Basic principles
1. The coexistence of and the difference between explicit and implicit knowledge.
2. The simultaneous involvement of implicit and explicit processes in most tasks.
3. The redundant representation of explicit and implicit knowledge.
4. The integration of the results of explicit and implicit processing.
5. The iterative (and possibly bidirectional) processing.
Auxiliary principles
1. The existence of a (rudimentary) metacognitive monitoring process.
2. The existence of subjective thresholds.
3. The existence of a negative relation between confidence and response time.

Although the auxiliary principles are not central, they are complementary. First, a stopping criterion is needed to decide whether the iteration is ended and a clear outcome is reached. This criterion is predicted by a basic metacognitive monitoring system that can evaluate the likelihood of discovering a solution, called internal confidence level (ICL). Furthermore, a threshold is needed to define the definitive result, which might vary depending on the demands of the work. Finally, it is presumed that there is a negative correlation between response time and ICL.

2.1.4 Creative Neurocognition

It is explained that creative cognition points out the cognitive processes behind creativity, which aims to understand how creative ideas are being produced (Beaty et al., 2016). Creative neurocognition further explores the brain basis of creativity (Abraham, 2019).

Creativity is an extensive and multidimensional phenomenon that is challenging to implement in any study, especially in cognitive neuroscience studies, due to methodological constraints. To begin with, the recording methods are sensitive to motor activities such as eye or body movement, because they lead to artifacts in the recorded brain activity, which is also the reason for the simplicity of collecting responses via pressing a button or verbal communication (Abraham et al., 2012). Another constraint is that neuroscience experiments require a large number of short trials to gather enough data to average over trials; however, it may not be possible for long durational creative tasks (Abraham et al., 2012). Moreover, careful consideration is required to determine appropriate control tasks that allow the separation of cognitive activities from each other but also should not be too easy or less demanding as compared to creative tasks (Abraham et al., 2012).

Unfortunately, cognitive neuroscience does not provide a powerful approach when creativity is addressed as a unitary phenomenon; this is because reliability in attaining specific processes to brain activations decreases when complexity increases (Benedek et al., 2019; Dietrich and Kanso, 2010). Yet, to deal with the methodological constraints, some factors need to be considered, such as the duration of a task, in which the tasks in the experiment might be designed in shorter segments to increase the possibility of the occurrence of cognitive processes related to the creative task. It also raises the accuracy of separating the creative response from other cognitive activities occurring during the task (Benedek et al., 2019). Furthermore, by adopting different approaches while collecting responses, such as self-paced, in which the thinking process and response moments are not separated to allow participants to respond at whatever time they create a solution, the flexibility required in the creative process can be increased (Benedek et al., 2019). Further, approaching creativity by dividing into its components rather than accepting it as a monolithic entity, appraisal of outcomes from cognitive neuroscience studies becomes more accurate (Dietrich, 2007).

Several systematic reviews of studies on creativity in the cognitive neuroscience domain have been undertaken. According to the study conducted by Benedek (2018), in which more than a hundred studies were investigated in terms of the tools, assessment methods, domains, and task types, it can be indicated that by specifying *a priori* assumptions, extracting cognitive processes related to different phases of the creative process, assessing outcomes of the process under investigation and consolidating results, cognitive neuroscience can advance our comprehension of how creativity emerges in the brain. Figure 2.3 represents the percentage of methods and tasks used in studies conducted between 1975 and 2018 on creativity (Benedek, 2018).

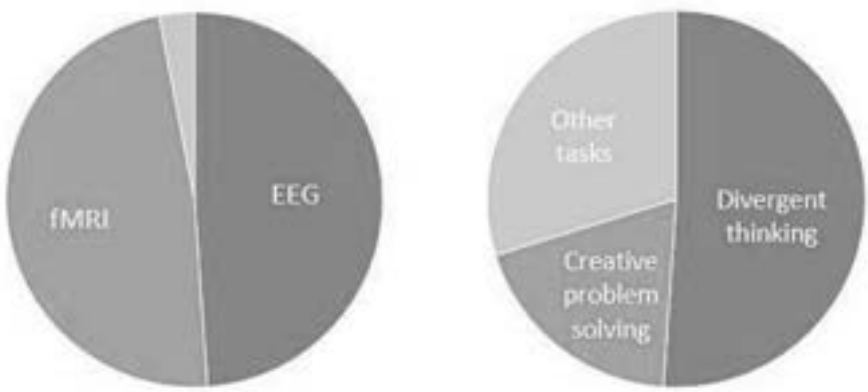

Figure 2.3 Methods and tasks used in experimentations conducted between 1975 and 2018 (Benedek, 2018, p. 26)

As it can be seen from Figure 2.3, the majority of studies employ EEG and fMRI while predominantly looking at divergent thinking and creative problem solving in the domains of engineering, musical creativity, and artistic performance (Benedek, 2018).

Another classification study conducted by Dietrich (2010) investigates 63 articles and presents studies under insight, artistic creativity, and divergent thinking as their foci. As stated by results, imaging studies demonstrate consistency, while, in general, it is hard to find overlaps between the findings of studies because of the lack of subdivision creativity into entities (Dietrich, 2010). Dietrich (2007) remarks that laboratory-based research on creativity has not been developed as much as other empirical research areas in cognitive psychology and neuroscience. He points out four outdated ideas, which are the results of approaching creativity as a monolithic entity, that need to be demolished to accelerate research in this area. The first is sticking to one dimension of the concept, divergent thinking, for 50 years to explain creativity. The second is the belief that creativity emerges in the right brain. The third is advocating that creativity is the result of unfocused attention, and the fourth is that creativity emerges from the altered states of consciousness (Dietrich, 2007). Furthermore, creativity studies use a wide variety of conceptions and employ different tasks under different conditions on the one hand, and creative expressions differ in quality on the other, which eventually may be the reason for the lack of overlapping results to be able to indicate where creativity takes place in the brain (Arden et al., 2010; Benedek et al., 2014).

It is thought that neuroimaging studies on creativity have both domain-specific and domain-general characteristics (Beaty et al., 2016). Based on this thought, it is needed to determine *cognitive processes central to creative cognition* (Jung et al., 2013). Runco (2014) approaches creativity as a bridge between basic cognitive processes that represent a nomothetic process, in which the concept shares universal commons and individual traits that can vary, such as intelligence and problem-solving.

Empirical studies on creative neurocognition try to unfold the brain-based mechanisms underlying the creative process. Regarding neural underpinnings, the ventrolateral prefrontal cortex (VLPFC) and inferior parietal cortex (IPC) are involved during retrieval and integration, and the dorsal prefrontal cortex (dorsal PFC) during evaluation (Figure 2.4). Goel (2010) also offers that the right prefrontal cortex (right PFC) plays a critical role when the problem space is broad, containing conflicting and insufficient information. Also, in their study of real-world design and planning tasks with an architect with a lesion in his right dorsolateral prefrontal cortex (rDLPFC), Goel and Grafman (2000) found out that the damage in his right DLPFC causes the incapability of coping with ill-structured problems. This view is supported by Gilbert et al. (2009), who studied an ill-structured problem-solving task with functional magnetic resonance imaging (fMRI) by comparing a design task (ill-structured) with a problem-solving task (well-structured). Their study reveals that rDLPFCs show remarkably greater activation during design tasks compared with problem-solving tasks (Gilbert et al., 2009).

Many studies suggest that Default Mode Network (DMN) (Mason et al., 2007; Christoff et al., 2009; Ritter and Dijkterhuis, 2019; Sripada, 2018), Executive Control Network (ECN) and Salience Network (SN) play a role in associative thinking. Fingelkurtz et al. (2005, p. 680) summarize the interaction of these three large-scale networks as follows: “DMN is theorized to support the generation of candidate ideas (via associative thinking and other memory-related processes), with SN involved in the identification of promising ideas, and ECN contributing to idea evaluation, selection, and modification”. The review of Beaty and Kennett (2023) also reveals the role of DMN in constructing free associations during idea generation. When it comes to goal-directed associations, the activity is observed in regions related to episodic memory retrieval and mental imagery, as well as the bilateral angular gyri of the DMN.

Looking at the studies conducted via EEG, there is a consensus on the importance of alpha activity (8-13 Hz) during the creative process (Jauk, Benedek, and Neubaer, 2012; Benedek, 2014). Alpha activity is associated with both rest and task performance (Arden et al., 2010). It is found that alpha power (i.e., Arden et al., 2010) is greater in creativity-related tasks when more creative people perform the task than less creative people, and when more creative ideas are generated as compared to less creative ideas (Benedek, 2018). Also, Fink et al. (2009) find stronger alpha synchronization, particularly in frontal regions when participants think of unusual uses of common objects. The relationship between creativity and alpha activity is explained by attentional focus and controlled memory retrieval (Benedek, 2018). Some studies link alpha activity to the internally directed attentional focus (Martindale, 1999; Benedek, 2018) and link the increased task performance with higher alpha activity (Fink et al., 2007, Fink and Neubauer 2006; Schwab et al. 2014). Some studies report hemispheric asymmetry in creative ideation tasks, suggesting a higher alpha power in the right hemisphere as compared to the left hemisphere (Martindale, 1984; Bowden and Jung-Beeman, 2003; Fink and Benedek, 2014; Schwab et al., 2014).

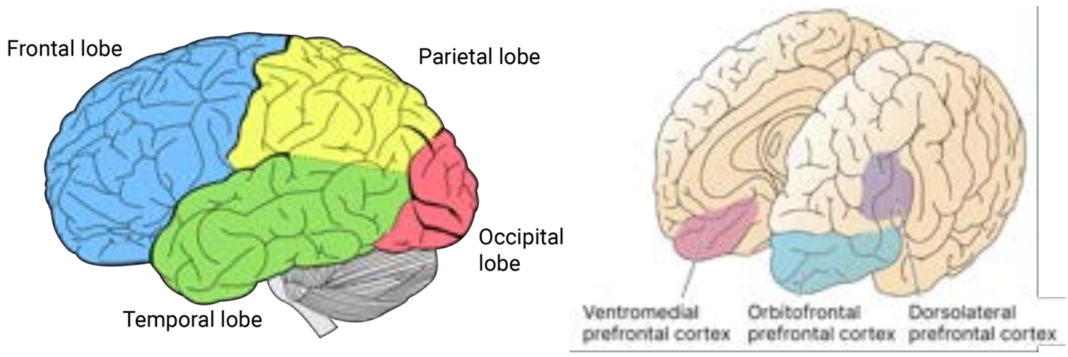

Figure 2.4 Anatomy of the brain and the parts of the prefrontal cortex

There are several models in the literature that draw neural mechanisms underlying the creative process that will be investigated further.

RISE model

The RISE model (A Neurocognitive Process Model of Idea Generation) tries to outline the process of creative idea generation by benefiting from the evidence from previous cognitive and neuroscience research (Benedek, 2018). Benedek (2018, p. 39) defines creative idea generation as "an open-ended, multiply-constrained search and integration process." As can be seen from Figure 2.5, retrieval, integration, simulation, and evaluation steps (RISE) iteratively occur and indicate the creative idea generation phase, whereas the first two steps take place for all complex problem-solving tasks.

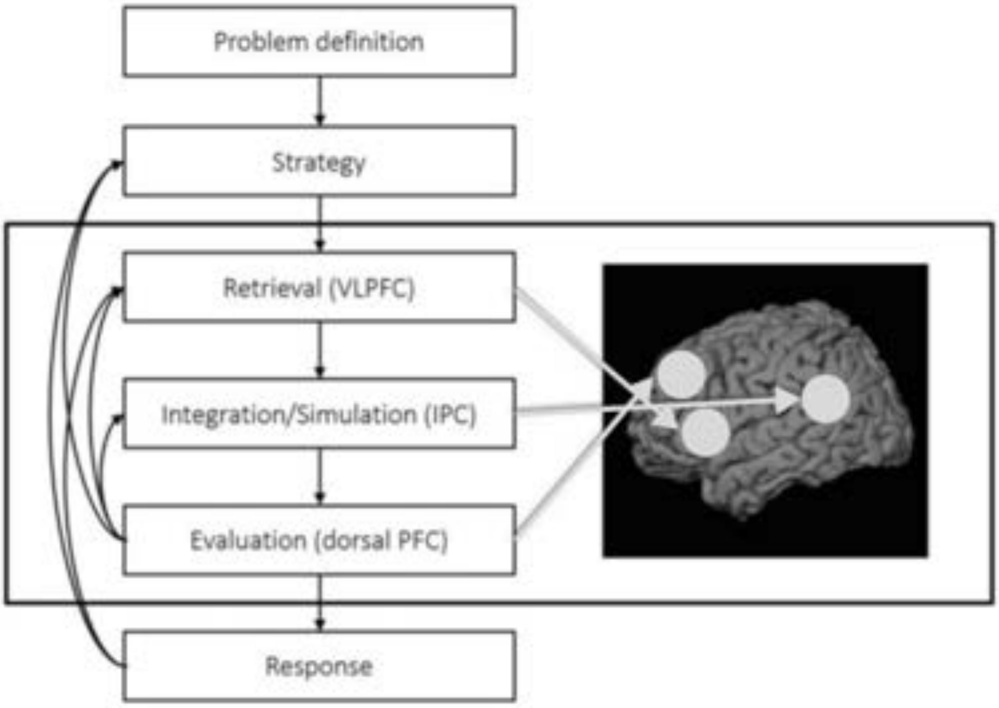

Figure 2.5 The RISE process model of creative idea generation where steps can be linked to brain activation in the ventrolateral prefrontal cortex (VLPFC), inferior parietal cortex (IPC), and dorsal parts of the prefrontal cortex (dPFC), respectively (Benedek, 2018, p. 39).

The model strongly connects with the Associative Theory of Mednick (1962) in terms of adapting the notion of resulting creative ideas by creating associations between remote concepts to the empirical study. It further proposes an interaction between generative (retrieval, integration, and simulation) and evaluative processes, which has consistency with the interaction between Cropley's (2006) divergent and convergent thinking, Campbell's (1960) and Simonton's (2010) blind variation and selective retention, and Finke's (1996) generation and exploration phases in the Geneplore Model (Benedek, 2018).

Neural Network Theory

Neural Network Theory tries to describe mental processes by using neuron-like components (Martindale, 1995). According to this theory, groups of neurons (or nodes) that are activated simultaneously indicate an association between them. Later, when one of the nodes is activated, the other clusters are engaged (Fairweather, 2011). Martindale (1995) emphasizes that major theories can be translated into neural network theories, and in doing so, it becomes visible that they share common grounds. For example, Campbell's theory of BVSR suggests that quasi-random thoughts cause the occurrence of creative ideas by chance. Martindale (1995) explains this view within the Neural Network Theory as constructing new connections between already actively connected networks with undirected connected networks. In the end, arousal takes place: "The activated nodes become extremely activated, and the connection strength between them is quickly increased" (Martindale, 1995, p. 254). He highlights that attention is too focused during the preparation phase of the creative process, which indicates the high activation of a few nodes that dominate consciousness. When it comes to incubation, the nodes coding the problem remain partially active. As mentioned before, when the person continues her/his daily life, new connections can be constructed with undirected networks. Those nodes that were partially active before become fully active and leap into attention. During the verification phase, the attention becomes too active again (Martindale, 1995).

Neuro-EII Theory

This theory is the neurobiological expansion of the EII theory explained in the previous chapter. It is based on the idea that both explicit (conscious, rule-based) and implicit (unconscious, associative) processes work simultaneously and interact in creative problem-solving (Figure 2.6). The theory relies on Wallas' four phases of the creative process and proposes how they are supported by distinct brain mechanisms. During the preparation and verification phases, the lateral prefrontal cortex and hippocampus are involved in rule-based reasoning and memory retrieval. During the incubation phase, the parahippocampal gyrus, and DMN activation take place to process memory implicitly. During the last phase, the anterior cingulate cortex is linked to the moment of insight.

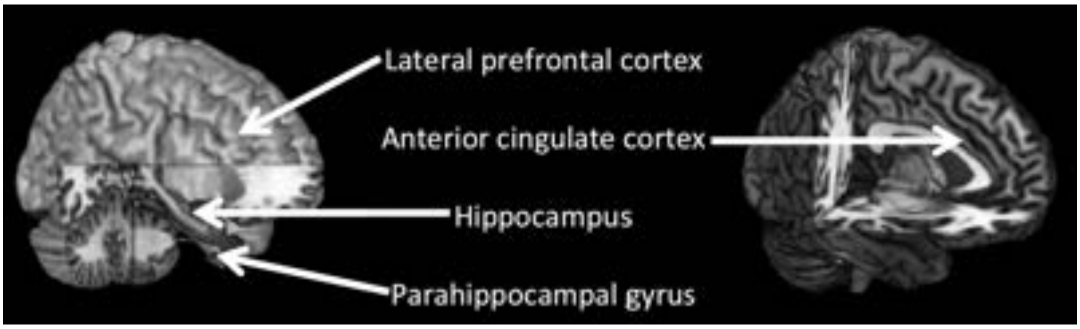

Figure 2.6 Neuro-EII theory model links the brain regions with phases of creative production (Helie, 2013, p. 6)

2.1.5 Divergent and Convergent Thinking

Even though creativity has been linked to divergent thinking tests, it is impossible to come up with working solutions without convergent thinking (Cropley, 2006). One of the first differentiations between convergent and divergent thinking in terms of operational and logical differences between them was made by Guilford (1956). Even though opposite views can be found, such as the Triangular Theory, which defends that convergent thinking is required at some level to support divergent thinking, the majority of the researchers in the area accept the duality (Acar and Runco, 2019).

The process of divergence requires lateral thinking in which the problem space is broadened, and various directions are explored (Acar and Runco, 2019). This is also the phase where novelty comes from. The process requires making new connections, taking risks, and being unconventional (Cropley, 2006). de Bono (1970) draws an analogy for describing the nature of lateral thinking. He finds the process similar to building a bridge. While building it, the parts might not be supported by each other; however, when finished, the parts fit each other, and the bridge becomes self-supporting. He makes a differentiation between lateral and vertical thinking as follows: “Vertical thinking moves only if there is a direction to move; lateral thinking moves in order to generate a direction (1970, p. 39).”

During the convergence phase, knowledge becomes the essential element to combine ideas sensibly, being aware of the pathways that go to the solution, and fulfilling the requirements as well as satisfying criteria (Cropley, 2006). This type of thinking is very useful when correct solutions are required (Runco and Acar, 2019).

Goel (2014) highlights the requirement of divergent and convergent thinking together to be able to solve real-world problems. When an imbalance of appraisal occurs, it means that the difference between well-structured and ill-structured problems and the equal importance of vertical transformations are ignored (Goel, 2014).

Thus, even though divergent and convergent thinking are sometimes seen as separate processes, their interaction is essential for solving problems and producing original work. While convergent thinking helps bring those concepts into clarity and make sure they satisfy logical and practical requirements, divergent thinking encourages investigation and the creation of new ideas. In the end, these two procedures work together to produce creative and practical answers in real-world situations.

2.1.6 Evaluating Creativity

Cropley (2000) approaches creativity-related concepts under three groups: person, product, and process. Kaufman, Plucker, and Baer (2008) organize their research based on the “Four P” model (Rhodes, 1961, as cited in Kaufman, Plucker, and Baer, 2008), which adds press (environment) as the fourth concept. Although Rhodes (1961) considers the 4Ps of creativity by correlating creativity with intelligence, the 4P model of creativity has been widely used. Runco and Kim (2011) further attempt to include persuasion as the fifth aspect of which social judgment and historical impact are argued. They investigate the creativity phenomenon within a framework that consists of two categories: creative potential and creative performance. While person, process, and press are classified under creative potential, product, and persuasion are approached under creative performance (Runco and Kim, 2011).

Tang et al. (2017) draw attention to the general approach in creativity studies that treat products as the dependent variables, while the process, person, and press are the independent variables, which place aside the valuable insights they carry about creativity. Still, the majority of the tests are focusing on products.

Measuring creativity can help individuals to become aware of their strengths at a smaller scale and understand the mechanisms of mind at a larger scale. Also, it gives a chance to build a terminology to communicate better about it and helps to identify talented people (Treffinger, 1996).

The metrics of assessing creativity at different levels need to be considered to fit the multidimensionality of creativity (Gero, 2011). Further, Guo, Ge, and Pang (2019) highlight the importance of researching the factors involving the evaluation of creativity as well. They believe that rater biases are underestimated, and cognitive mechanisms underlying creativity can be applied to the evaluation of creativity as well. Because, according to their findings, highly creative people tend to find ideas less creative and likely to relate general ideas with each other easily in terms of their semantic distance.

Measuring creativity not only helps individuals recognize their strengths but also aids in understanding cognitive mechanisms and addressing rater biases. Given the complexity of creativity, multidimensional approaches are necessary to capture its full scope.

2.1.6.1 Evaluating Creative Process

Tests for creative process evaluation mainly approach the creative process as a divergent thinking process. The first example of divergent thinking tests goes to 1896, which includes open-ended questions developed by Binet (Sawyer, 2012). During the 1950s, Guilford built a model that describes distinct types of divergent thinking with the Structure of Intellect (SOI) model (Guilford,1956; Kaufman et al., 2008). The model includes more than 180 types of divergent thinking and creates a base for further models of DT tests. He highlights that divergent thinking should include four abilities: fluency, flexibility, originality, and elaboration (Guilford, 1950).

After his introduction to DT, many successors in the era adopted it for the development of different divergent thinking tests. Torrance Test of Creative Thinking (TTCT) was one of them that depended on divergent thinking and was developed by Torrance in 1966 (Kim, 2006). The test includes verbal and visual assessments, which are in low correlation with each other, indicating that they measure two different constructs of creativity (Sawyer, 2012). The test is also seen as reliable in terms of test-retest reliability (Kim, 2006).

Another example of DT is the Alternate Uses Task developed by Guilford (Russ and Dillon, 2011). It is seen as a suitable evaluation method for divergent thinking because it requires participants to generate ideas for open-ended problems (Benedek et al., 2019). It generally uses everyday objects. The test is widely used in cognitive neuroscience because it is a well-tested task (Benedek, 2018).

Kaufman and his colleagues (2008) point out that the reasons behind the popularity of divergent thinking tests are not mainly due to the creative process being considered equal to divergent thinking for a long time but also because many of the leading figures in the research area centered on DT. Also, the dominance of intelligence research around the 1950s forced creativity researchers to follow a corresponding way as well.

Nevertheless, divergent thinking tests are not satisfactory enough to deduce the existence or level of creativity. As Sawyer (2012) points out, DT does not have validity for real-world creativity, and there is a consensus among researchers on this matter. Besides, it seems problematic in terms of test-retest reliability. Another problem with DT is that it is time-consuming to evaluate the results of the test by considering the four different factors mentioned above. Different evaluation methods were generated afterward to reduce the time of evaluation (Silvia et al., 2009; Sawyer, 2012). Kaufman et al. (2008) recommend considering the domain-specificity of adaptation of DT and also minimizing response bias as well as providing a distinction between score categories.

2.1.6.2 Evaluating Personal Creativity

Evaluation of personal creativity focuses on personal traits such as motivation, personality, intelligence, and knowledge (Kaufman, Plecker, and Baer, 2008). Inventories, self-reporting techniques, and tests are used to evaluate creative personality.

Self-report instruments are generally used to evaluate people's standing or performance regarding the relevant trait quantitatively (Robson, p. 307). In creativity research, researchers suggest employing creativity self-reports cautiously, concerning the tendency of individuals to exaggerate or lie in answers in order to appear better (Kaufman, 2019). Furthermore, individuals may not be aware of what is being questioned (Reiter-Palmon et al., 2012).

Kaufman (2019) addresses self-reports, which he calls creativity self-assessments (CSA), as having four categories: activities, evaluation, process, and beliefs. Activities inquire about people's involvement in creative activities or behaviors. Evaluation focuses on how people judge their work in terms of creativity. The process examines various aspects of the creative process, including ideational behaviors and methods of thinking. Beliefs assess people's thoughts (both implicit and explicit) about their creativity or the idea of creativity itself.

The Componential Theory constructed by Amabile (1996) proposes that generating a creative response requires four components, three of which point out personal traits and one of which indicates the qualities of an environmental setting. Components related to personal traits are domain-relevant skills, creativity-relevant processes, and intrinsic task motivation (Amabile, 2012).

The Investment Theory constructed by Sternberg and Lubart (1991) establishes an analogy between investment, which profits from buying something low and selling high, and creative performance as well as the level of investors, which can be large or small scale, and the level of creativity, which indicates high and low creativity (Sternberg and Lubart, 1991). According to them, six sources can be found to contribute to the generation of creative ideas, which are intelligence processes, knowledge, intellectual styles, personality, motivation, and environmental context. Creativity arises from the confluence of these six sources, which can also be seen as incomes and transformed into creative performances by using them effectively.

Another assessing method that focuses on creative ability is the Remote Associates Test, invented by Mednick (1968), which expects participants to find remote associations in the verbal domain. The test is seen as a measure of both divergent and convergent thinking (Vartanian, 2011). The test is based on the Associative Theory, which was constructed by Mednick (1962) and proposes that creative ideas come from semantically distant combinations, and creative people are better at relating those remote ideas to form a new one. Mednick (1968) defines creative thinking as the "forming of mutually distant associative elements into new combinations which are useful and meet specified as well as unforeseen requirements" (p. 213). The test requires a problem-solver to reach a meaningful link between three cue words that seem unrelated at first sight. Each word set includes three words, and the participant is asked to find a fourth word that connects all three. For instance, the words *tooth*, *potato*, and *heart* can all be linked by the word *sweet*, as in *sweet tooth*, *sweet potato*, and *sweetheart*. Similarly, *illness*, *bus*, and *computer* are connected by the word *terminal*, forming *terminal illness*, *bus terminal*, and *computer terminal* (the examples are taken from Bowden and Jung-Beeman, 2003). The participant's task is to discover these linking words, demonstrating their ability to find connections between seemingly unrelated ideas. Even though the test is powerful and used in many empirical studies, including studies in the area of cognitive science, it has some disadvantages, such as the difficulty for non-native speakers and the high level of correlation with intelligence (Sawyer, 2012). The high correlation between convergent thinking and verbal ability tasks also threatens the discriminant validity of the test (Runco, 2014).

2.1.6.3 Evaluating Creativity in Products

The Consensual Assessment Technique, one of the most applied methods for assessing creativity, assesses the level of individual creativity by evaluating the products of creative processes. The test gives participants some amount of time and asks them to generate artwork such as a poem or a sketch. After that, the outcomes are rated by experts in the domain. This technique was first used by Csikszentmihalyi in his doctoral dissertation (Sawyer, 2012). The inter-rater reliability shows a high correlation when judges are experts; however, ratings of novices do not highly correlate (Sawyer, 2012).

The Creative Product Semantic Scale (CPSS) was developed based on an early scale by Besemer and Q'quin (1989) called The Creative Product Analysis Matrix (CPAM), aiming to provide a more practical and standardized way to measure product creativity. It makes simplifications on CPAM's dimensions. Both scales approach evaluation across three dimensions with different subscales: novelty, resolution, elaboration, and synthesis. The scale can be applied in various fields, including engineering, design, and arts.

2.2 Creativity in the Design Process

The design process is a creative problem-solving process that includes a series of iterative events, methods, and processes. Best (2006) defines design as a "rigorous, cyclical process of inquiry and creativity (p. 112)." The process begins with a problem definition and follows a series of steps until a solution that fulfills the requirements is proposed. Curry (2017) describes designing to be an observable behavior because the process follows similar patterns and methodologies that come to the aid of discovering the solution area. Yet, the design process differentiates from other problem-solving processes as it requires redefining the problem at hand before processing it into further phases. The process contains the tacit knowledge of a designer, who may not be able to explain their approach step by step externally but knows how to tackle it (Cross, 2007). Furthermore, design problems are not just distinguished from other problems in terms of the approach of a designer to the problem but also because of the nature of the problems, which are ambiguous and ill-defined, and the solution is not unique and apparent either. Another point highlighted by Lazar (2018) is that the difference does not just lie under the ill-structuredness but also the requirement of making connections between problem and solution with a certain level of abstraction as well as the existence of individual factors during the creative process. Although the levels of structuredness, complexity, and abstractness depend on the problem at hand, the design process requires the formulation of problem structure relevantly from the ill-defined problem given in the design brief. Eventually, it requires advanced skills in information gathering, structuring, and making judgments to move on to solution generation (Cross, 2007).

The design process can be represented under several phases that are followed iteratively. Design Council's (2024) Double Diamond Model is a recognized model within the design community and represents the design process under four main phases of divergent and convergent thinking. The model has its roots in the Creative Problem Solving Model developed by Osborn in the 1940s (Creative

Education Foundation, n.d.). The model consists of discovery, definition, development, and delivery phases that can be followed iteratively.

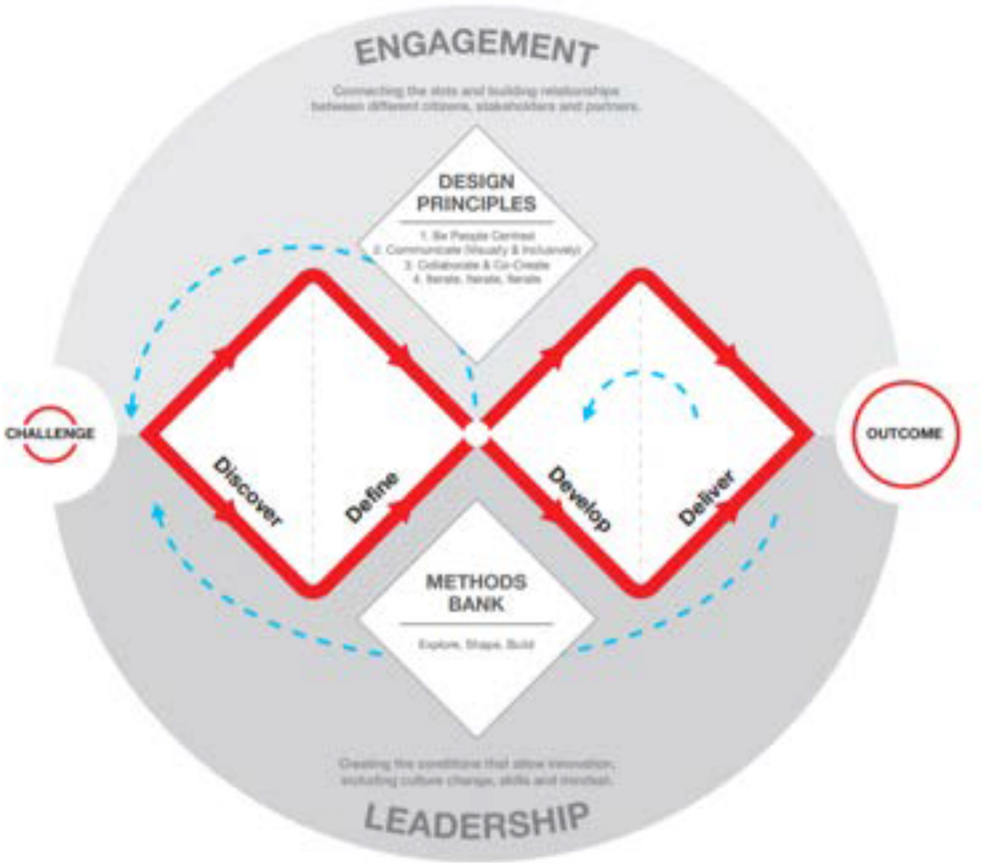

Figure 2.7 Design Council's Double Diamond design model (Design Council, 2024)

The model outlines four distinct phases as follows. The process begins with the *discovery* phase, where the challenge is explored, and user needs are identified. This phase is succeeded by the *definition* phase, during which findings are consolidated, and the alignment between the problem and user needs is clarified. The outcome is a well-defined design brief that articulates the challenges with precision, grounded in prior insights. Next is the *development* phase, a stage dedicated to generating, testing, and refining potential solutions. Finally, the *delivery* phase sees the selection of a single solution, which is then prepared for launch. Notably, the development phase aligns with the value or innovation aspect of creativity, while the delivery phase reflects the functionality or usefulness dimension of creativity.

The process of generating as many alternative solutions as possible also corresponds to synthesis in the basic design cycle (Archer, 1968; Jones, 1992; Lawson, 2006; Roozenberg, 1995). Synthesis refers to the least solid phase in the design cycle because creativity plays the most crucial role, and a combination of separate ideas into a whole takes place (Annemiek, Daalhuizen, and Roos, 2014). According to Goldschmidt (2014), creativity in design is rooted in the strong connection between the generation of new ideas and the early phases of the design process. This highlights the importance of linking new ideas to those developed earlier. The connection between the design criteria identified at the beginning and the problem space explored determines the inventiveness of fnew ideas.

2.2.1 Nature of Design Problems

Design problems are often regarded as wicked problems, where solutions are not *a priori,* and problems need to be formulated before attempting to solve them (Rittel and Weber, 1973). Dorst (2011) makes a distinction between design problem-solving and conventional problem-solving from a design thinking perspective. He explains the differences by drawing an equation in which the sum of 'what' and 'how' leads to 'result'. When the conventional problem-solving approach fails to follow this equation, where inductive or deductive reasoning is followed, due to the complexity of a problem, design reasoning can deal with this complexity by deconstructing the problem (what) first, and if not enough, then reframing the how and finally leading to value rather than a result. Here, what he meant by design reasoning is the abduction. What makes abduction different from other types of reasoning is that, first, it aims to create value for others rather than reaching a result, and second, there is a more challenging form of abduction, in which the designer needs to figure out 'what' to create where there are no described working principles but only the value that is wanted to be reached is known. Dorst (2011) highlights that this second form of abduction is associated closely with design problems that are open and complex.

Goel (2014) investigates the design problem-solving process with its underlying cognitive mechanisms and proposes that the design problem-solving process requires both lateral and vertical transformations, which correspond to cognitive divergent and convergent phases. Goel also makes a distinction between well-structured and ill-structured problems in terms of phases and cognitive processes involved during the process. He defines the idea-generation process in which solutions are generated to answer ill-structured problems:

> "It is a phase of "cognitive way-finding," a phase of concept construction, where a few kernel ideas are generated and explored through lateral transformations. [...] A lateral transformation is one where movement is from one idea to a slightly different idea rather than a more detailed version of the same idea" (Goel, 2014, p. 6).

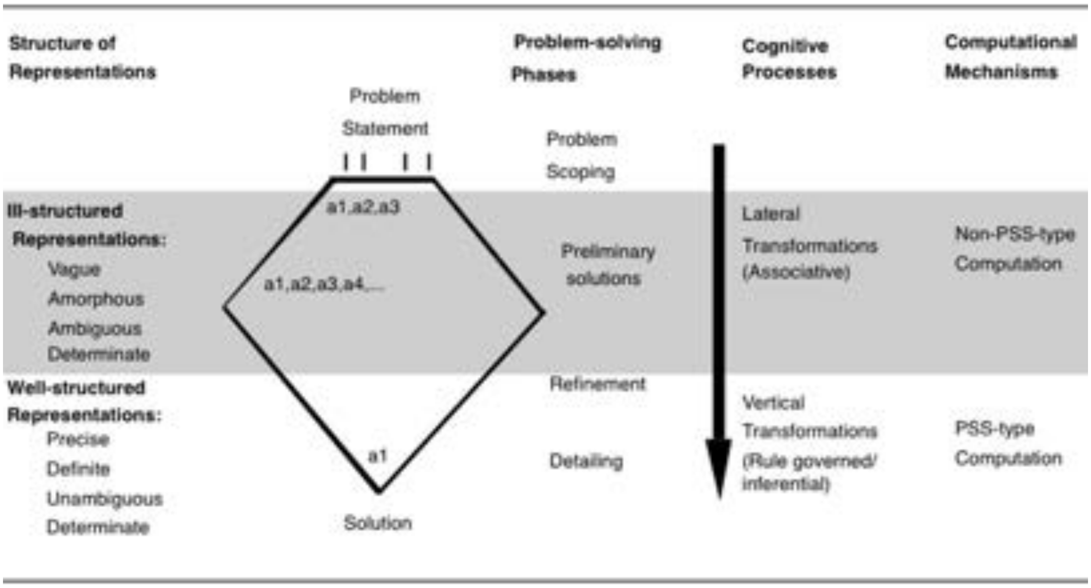

Figure 2.8 Problem-solving phases of different representation structures, corresponding cognitive processes, and computational mechanisms (Goel, 2010, p. 5)

As can be seen in the figure, lateral transformation requires finding answers to ambiguous and ill-structured problems and extending the problem area with preliminary solutions by constructing associations, while vertical transformation entails proposing solutions for well-structured and pre-defined problems and narrowing down the solution area with rule-governed and goal-directed processing. By computational mechanisms, problem-solving is approached as a form of information processing relying on Newell and Simon's Physical Symbol System (PSS) hypothesis, suggesting that problem-solving can be explained as symbol manipulation. While non-PSS-type computation corresponds to lateral transformations following associative and undirected thinking, PSS-type computation corresponds to vertical transformations following rule-based and inferential thinking.

In his seminal text, Jonassen (2000) defines design problems as the most complex ones among different types of problems. This complexity requires a domain-specific approach. He addresses the problem-solving process based on their structure, which is well-structured and ill-structured, domain specificity and complexity. He suggests that the problems are distinguished from each other, and each of them requires a different kind of cognitive processing and requirements. Therefore, information-processing models or general problem-solving models do not apply to design problems. He follows a constructivist approach in which the solver constructs knowledge specific to that context.

Although ill-structured and ill-defined are terms sometimes used interchangeably, there is a slight difference between them. Ill-structured problems have limited parameters and involve uncertainty about the necessary concepts, rules, and principles for solving them. However, ill-structured problems usually have an identifiable solution that can be evaluated against established criteria. Ill-defined problems have neither a predefined solution nor problem constraints, and criteria are defined clearly (Jonassen, 1997). Well-defined problems, on the other hand, encapsulate all information that is required to resolve them in their presentation, while ill-defined problems need experience and knowledge to be resolved (Taylor and Workman, 2021). Well-defined problems have a clear initial statement, a goal statement, and a set of procedural operators (Jonassen, 2000).

Table 2.3 presents a framework for understanding problem-solving in design by outlining how problem variations, representation, and individual differences contribute to a designer's effectiveness. Design problems are often ill-structured, complex, and abstract, demanding flexible, context-specific solutions. How the problem is represented, including social, cultural, and contextual cues, guides the designer's approach and interpretation, which is crucial since design challenges rarely have straightforward solutions. Individual differences such as domain knowledge, cognitive styles, and motivation further influence problem-solving abilities, allowing designers to creatively navigate ambiguity and complexity. Together, these elements form a designer's overall problem-solving skill, enabling them to address the unique demands of design challenges innovatively.

Table 2.3 Jonassen's schema on the contributors of problem-solving skills (2000, p.66)

Problem Variations →	Representation →	Individual Differences =	Problem Solving Skill
Ill-structuredness	Context	Domain knowledge	
Complexity	social	familiarity	
Abstractness/	historical	perplexity	
situatedness	cultural	experience	
(domain specificity)	Cues/Clues	Structural knowledge	
	Modality	Procedural knowledge	
		Systemic/conceptual knowledge	
		Domain-specific reasoning	
		Cognitive styles	
		General problem-solving strategies	
		Self-confidence	
		Motivation/perseverence	

Reed (2017) classifies problems into three categories based on the cognitive skills required to come up with solutions. *Arrangement problems* require rearranging components to meet the criteria necessary to solve the problem, such as making a word out of the displaced letters. *Transformation problems* need to transform an initial state into a goal state in which the goal state is predefined, such as the Hanoi

Tower problem. *Inducing structure problems* is a problem type that requires discovering relationships between sub-components of the problem in order to provide a solution to the problem.

According to his psychosomatic approach to problem-solving, Kreitler (2013) proposes four different approaches to problem-solving based on the theory of meaning. The formal approach is applied in problems with clearly defined rule sets and steps, where the problem solver needs to move from one construct to another logically. The analogical approach is based on transformation into solution space by constructing relations with indirect inputs. The paradigmatic approach relies on previously solved problems to reason the new problem. According to Kreitler (2013), case-based problem-solving, induction, and holistic problem-solving are the three domains to which the paradigmatic approach can be applied. Lastly, the symbolic approach is based on connecting the responses to inputs using statements with different levels of abstraction and different from the input's characteristics.

According to their Explicit-Implicit Theory (EII), which is investigated further in section 2.3, Helie and Sun (2013) advocate that as the problems get complex, it is not possible to close to a solution by following a step-by-step explicit process; rather, one needs to take an implicit or intuitive approach. By implicit processes, they point out an incubation in which more hard-to-verbalize and rather difficult-to-reach knowledge is employed. In contrast, explicit processes are easy to reach and verbalize.

Another contributor to problem-solving in design is the designer's mindset or mental construct that points out the interrelated elements of approaching the problem, which contains the interpretation of the task, interpretation of the context, understanding of the theory of the method, imagining the use of the method, and understanding the result of the method (Andreasen, 2003). Moreover, Casakin and Kreitler (2013) highlight the effect of one's motivation on design problem-solving. For them, motivation is one of the main contributors to having flexibility in design, which enables designers to restructure the problem parameters, overcome fixation, and encourage the investigation of a variety of alternative design solutions.

Figure 2.9 attempts to represent the relationship between different classifications of problems. Knowledge-rich problems require additional information and domain-specific knowledge to find solutions, and these problems tend to be ill-structured. Knowledge-lean problems, on the other hand, tend to be well-structured because the information is inherent, and it does not generally require an extensive memory search (Taylor and Workman, 2021). A similar perspective to knowledge-based problem classification can be found in Jonassen's (2000) approach to problems. For him, one of the properties affecting the problem-solving process is individual differences. By that, he points out the familiarity that the problem-solver has with the problem at hand. As familiarity increases, one may automatically develop problem schemas and transfer the knowledge of previous problems into a new but familiar one.

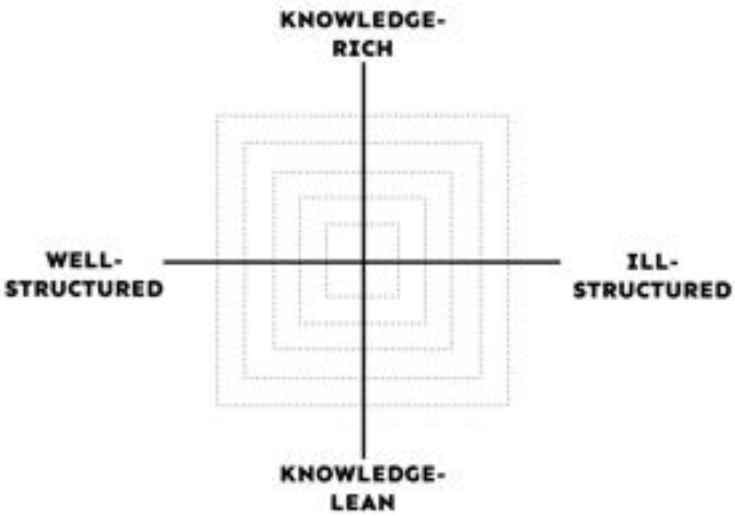

Figure 2.9 Classification of problems

2.2.2 Idea Generation Methods

There are more than a hundred idea-generation methods that can be found in the literature. Whereas some of them focus on the particular phase of idea generation, some of them approach the design process holistically. The ultimate goal of idea generation methods is to ease the exploration of the problem area, increase the number of ideas, and assist innovation.

Smith (1998) argues that it is needed to first apprehend idea generation methods in terms of "active ingredients," which indicates the necessary mechanisms to support the generation of ideas. He proposes three types of idea-generation devices among fifty methods which are strategies, tactics, and enablers (Smith, 1998). Moreover, by identifying mechanisms on which idea-generation methods are based, it can be possible to promote their effectiveness by offering a better fit between methods and tasks (Smith, 1998). Similarly, Hernandez, Shah, and Smith (2010) propose that by understanding the components of methods, variables that take a role in the interaction with a person or a team, and the relationship between process and outcomes, it seems possible to propose particular methods to use under particular conditions.

Shah, Kulkarni, and Vargas-Hernandez (2010) classify idea generation methods into intuitive methods and logical methods. The former works with the mechanism by which unconscious thought processes of the mind are stimulated. Some of the examples of this type of method are Morphological Analysis, Brainstorming, 6-3-5, and Synectics. The latter works with the decomposition of the process in a systematic way to analyze problems. TRIZ and FORD can be given as examples of this category (Shah, Kulkarni, and Vargas-Hernandez, 2000).

Another study conducted by Kirjavainen and Hölttä (2020) finds two mechanisms underlying idea generation methods: implementation mechanisms and idea-promoting mechanisms. The former indicates methods that are more concerned with the technical side of the process, such as the contributors and the duration of the process, while the latter focuses on creating ideas by stimulating cognition (Kirjavainen and Hölttä, 2020). Idea-promoting mechanisms are then subdivided into two: idea sources in which the cognitive processes are triggered by different mechanisms and processes in which the new ideas are facilitated by adding new phases to the process (Kirjavainen and Hölttä, 2020).

In conclusion, while there are numerous idea-generation methods available, knowing the fundamental processes that underlie them is essential to their efficacy. By classifying these methods and identifying their key components, the methods can be matched effectively to specific tasks and contexts. Whether intuitive or logical, each method offers unique strategies for stimulating creativity and innovation, ultimately enhancing the idea generation process. Yet, there are still areas to be explored, such as the effect of imagination, knowledge, and expertise in applying a specific method (Sarkar and Chakrabarti, 2017).

2.2.3 Evaluating Design Creativity

Specifically mentioning evaluating design creativity, several different approaches can be found in the literature. Sarkar and Chakrabarti (2011) propose that the measure of creativity in products should focus on product novelty and product usefulness since the central components of creativity are novelty and usefulness. They use the Function-Behaviour-Structure (FBS) model, first offered by Gero (1990), as a basis for ascertaining novelty. Along with the FBS, they use the SAPPhIRE model that was developed by Chakrabarti et. Al. (2005) determined the relative degree of novelty in which they propose that the FBS model is lacking in relating functionality criteria with the product's novelty. For usefulness, they define three criteria, which are the level of importance of use, rate of popularity of use, frequency of use, or duration of benefit.

Christensen and Ball (2016) focus on design critiques and the criteria that affect evaluative practice. They approach this evaluation by considering three dimensions, which are originality, functionality, and aesthetics. They also advocate that functionality and aesthetics should be process-oriented since the design process is continuous. Their research makes use of the data from a design critique session between students and supervisors.

Yuan and Lee (2014) advocate that most creativity measures focus on the outcome, not the process, which is where creative ideas are born. Although they use CAT to assess the creativity of the outcomes and protocol analysis to quantify the process, they propose a more inclusive and quantitative approach to the assessment and examine the correlation coefficient between the factors of the creative process and design outcomes.

Redelinghuys and Bahill (2006) propose a framework for assessing creativity in both individual works and among design teams. The Resource-Effort-Value (REV) framework implicates the designer’s background as a potential for the solutions to the problem, the designer’s effort to solve the problem, and the outcome created by them.

Metrics for measuring ideation effectiveness that is developed by Shah et al. (2003) focus on four attributes: novelty, variety, quality, and quantity. It provides an empirical framework with well-defined metrics that can be applied in engineering design, product design, or design education.

Another evaluation method applicable to engineering and design proposed by Dean et al. (2006) utilizes four metrics to evaluate how creative the products are: novelty, workability, relevance, and specificity. Each primary dimension is further divided into two well-defined sub-dimensions, as outlined in their study. They adopt a four-point scale for each sub-dimension and require two raters to evaluate products.

Table 2.4 Main and sub-dimensions of the evaluation method by Dean et al. (2006, p. 667).

Construct	Range	Formula
Novelty	2-8	Originality + Paradigm relatedness
Workability	2-8	Acceptability + Implementability
Relevance	2-8	Applicability + Effectiveness
Specificity*	2-6	Completeness + Implicational explicitness

The linkography method developed by Goldschmidt (2014) maps the thought process based on moves in a sequential way to analyze a design process. It makes use of nodes and forward/backward links to generate a graph of a network in which the complexity of design thinking can be explored.

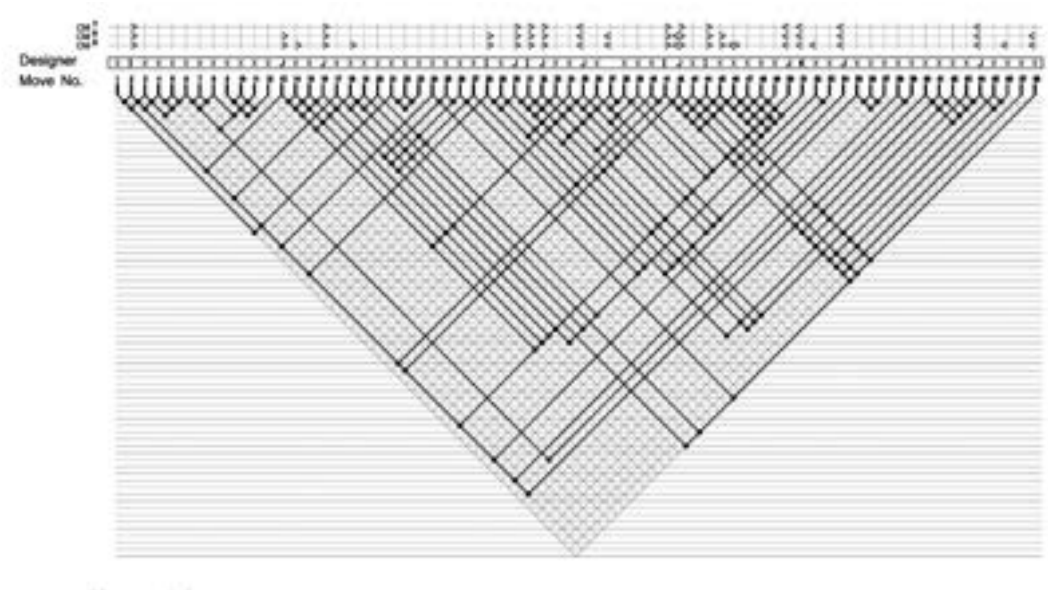

Figure 2.10 Linkograph example (Goldschmidt, 2014, p. 114)

In this graph, the nodes represent the designer's moves, and the links show how different moves influence and connect. She emphasizes that moves with more links are the indicators of key points that affect the solutions. Also, while a backlink represents convergent thinking, a forelink represents divergent thinking. Further, if a move is more interconnected, as between 28 and 54 in Figure 2.11, it contributes to a creative design synthesis. Goldschmidt (2014) advocates the design process is the combination of divergent and convergent thinking that occurs in cycles. The graph allows the identification of how divergent and convergent thinking takes place during the thinking process because creative ideas must be developed upon examining the earlier work and thoroughly discussing the previous design criteria.

In summary, evaluating design creativity requires a multifaceted approach, as demonstrated by the various frameworks and methodologies outlined in the literature. The diversity of approaches, from quantitative metrics like Shah et al.'s to process-based methods such as Goldschmidt's linkography, highlights the complexity of capturing creativity in design. Therefore, a comprehensive evaluation of design creativity should account for both the outcomes and the processes that generate those outcomes.

2.2.4 Knowledge and Expertise in Design

Expertise and individual differences are the factors that contribute to problem-solving. Expertise is seen as a product of experience, which assists the process of applying collected information to the solution space (Casakin and Levy, 2020). While novices attempt to apply a depth-first strategy to the problem space for solving a problem sequentially, as the level of expertise rises, a more top-down (breadth-first) process takes place (Cross, 2007). Moreover, as the familiarity grows, using internal and external representations becomes easier, and the designer becomes more confident (Eastman, 2001). Similarly, while experts experience a more fluid and balanced time spent on problem formulation and solution phases, novices are more likely to spend less time on problem formulation activities and fail to produce better design solutions (Christensen and Ball, 2019). Furthermore, Goldschmidt (2014) highlights that experts can shift between convergent and divergent thinking frequently by interconnecting and synthesizing them, which is something that novice designers cannot do without experience, domain-specific knowledge, and tools.

Domain expertise is seen as the key to recognizing the statements and retrieving related information to generate solutions more automatically (Sweller, 1988).

Wiley (1998, p. 716) explains the background of this as follows: "The organization of domain knowledge in a way that is accessible, proceduralized, integrated, and principled enables experts to excel at memory and problem-solving tasks in a number of characteristic ways." Enhanced memory stems from experts' ability to recognize and store patterns, which makes it easier for them to recall large amounts of domain-specific information efficiently. They have encountered patterns and configurations frequently through experience, and this experience allows experts to retrieve and apply relevant information quickly (Anderson, 2010).

There are some situations where novices outweigh experts in terms of their performance, such as when dealing with domain-general problems and when it comes to self-judgment of their performance (Wiley, 1998). Wiley (1998) also questions the effect of applying domain knowledge when attempting to solve a problem, which may act as a mental set that might invoke a fixation on a problem.

From a cognitive psychology perspective, expertise is seen as a result of skill acquisition. The process of skill acquisition progresses in three stages: cognitive stage, associative stage, and autonomous stage. During the cognitive stage, learners rely on declarative knowledge, consciously thinking through facts and instructions about how to perform a task. During the associative stage, errors are detected and eliminated, as well as meaningful connections that would progress through a successful performance are strengthened. This is also where learners start to develop procedural knowledge. The last step involves the automatization of performance, in which no conscious effort is needed anymore (Anderson, 2010).

Regarding the knowledge types involved in this skill acquisition, Venselaar et al. (1987, as cited in Wong and Radcliffe, 2000) analyze four types of knowledge under three categories focusing on the domain (Table 2.5). While declarative knowledge stands for knowing what the facts are, procedural knowledge corresponds to knowing how to use these facts and formulas effectively. Situational knowledge points out knowing when and where to apply the facts and formulas, and strategic knowledge consists of the use of heuristics in terms of solving design problems and guiding the application of relevant knowledge and methods to achieve desired outcomes.

Table 2.5 Categorization of knowledge by Venselaar et al. (1987, as cited in Wong and Radcliffe, 2000, p. 499)

	Domain-specific basic knowledge	**Domain-specific design-knowledge**	**General process knowledge**
Declaration knowledge	Knowledge of facts and formulas	Knowledge of design and methods	Knowledge of methods to optimise the process
Procedural knowledge	How to use these facts and formulas	How to use these design facts/methods	How to use general optimisation methods
Situational knowledge	When and where to use this basic knowledge	When and where to use this design knowledge	When and where to use this process knowledge
Strategic knowledge	Knowledge of algorithms and heuristics of relevant domains	Knowledge of heuristics in solving design problems	Knowledge of algorithms and heuristics in problem solving

2.3 Incubation

In *The Art of Thought*, Wallas (1926) introduced the concept of incubation as one of four essential stages in the creative process. Since then, incubation has become a fundamental element in many creativity models, recognized for its role in allowing insights to emerge when conscious efforts are set aside. Numerous theories attempt to explain the phenomenon, and empirical studies have further refined our understanding, showing that incubation can improve creative performance by freeing the mind from rigid thought patterns and facilitating spontaneous access to relevant memories or novel associations. This section provides a review of incubation studies, with a focus on both general research and design-specific applications, and proposes new hypotheses that build on these findings to explore incubation's role in fostering innovation.

2.3.1 Defining Incubation

Incubation is a time span in which the problem is left aside. It is a phenomenon that people encounter as well as a process that results in the experience that is being experienced (Smith, 2011). Although there is no doubt about the occurrence of the phenomenon, the mechanisms or operations that cause the incubation effect are still under investigation.

In their meta-analysis of more than one hundred studies, Sio and Ormerod (2009) find support for the occurrence of the incubation effect. It is revealed that if a problem at hand requires the involvement of higher-order cognition, such as systematic decision-making and evaluative thinking, then leaving the problem aside is beneficial for creative performance (Seifert et al., 1995). This is called the incubation effect. Although, in a traditional sense, these breaks are given when the problem gets to an impasse, there is theoretical evidence that the incubation period provides enhanced performance, especially for creative problem-solving processes, even without experiencing an impasse. Smith (2011, p. 654) constructs an analogy between the process of incubation, in which incubation is defined as "an artificial means of supporting the development of a fragile developing system," with the process of fertilization of an egg. He follows:

> "This unseen development has served as an analogy for the notion that unconscious processes in the mind develop insightful ideas bit by bit, out of sight of the conscious mind, until at long last, miraculously, an insight emerges into consciousness. The analogy is a compelling one; unfortunately, there is no scientific evidence that unconscious cognitive processes autonomously put together the necessary steps for the emergence of an insightful idea (Smith, 2011, p. 654)."

Drawing on another contributor to incubation, Orlet (2008) highlights that the motivation of the problem solver might affect the occurrence of the incubation effect. He points out that: "… incubation requires both intense, focused intellectual work and great personal interest in attempting to solve a seemingly unsolvable problem and the conscious temporary abandonment of intense theoretical preoccupation with the specific problem" (p. 299). The personal interest he mentions is similar to *willingness* in Barr et al.'s (2014) study on reasoning. In their study, they explore the variances in individual differences relying on dual process theories, in which the thinking is approached as the combination of autonomous and intuitive processing (Type 1) and analytical and deliberative processing (Type 2). They suggest that the engagement of willingness in Type 2 processing is crucial to generating novel ideas in a controlled way instead of relying on intuition or automatic responses only.

Several theories and hypotheses on the mechanisms of the incubation effect are proposed, some of which evoke more attention and scientific evidence. Table 2.6 shows theories and hypotheses of incubation in different scientific areas.

Table 2.6 Theories of incubation, advocators, and their definitions

THEORY / HYPOTHESIS	ADVOCATOR	DEFINITION
Unconscious work	Wallas, 1926	Incubation as a break to allow unconscious mind to work on the problem after conscious work. This enables problem solvers to form a creative solution unconsciously and eventually emerge into conscious awareness as a complete idea
Remote Association	Mednick, 1962	Incubation as a period for allowing time to eliminate conventional solutions that addressed before and stored in the long-term memory of the problem solver. This enable problem solver to eliminate the stereotypical solutions and remove the blocks on the path of finding the correct solution.
The selective forgetting / Problem-space forgetting	Simon, 1966; Smith and Blankenship, 1989, 1991; Smith 1995	Incubation as a break to help reducing the influence of irrelevant ideas by allowing time for the mind to suppress them. This enables problem solvers to approach the problem with a fresh perspective, making the problem-solving process easier.

Table 2.6 (con't)

Low cortical arousal	Martindale, 1990	Incubation as a trigger for defocused attention to construct remote associative thoughts. This enables problem solver to lower arousal levels and widen the search in a larger mental representations.
Opportunistic assimilation	Seifert et al., 1994; Smith and Dodds, 1999	Incubation as a period for unresolved problems waiting in long-term memory to be triggered by external stimuli. This enable problem solver to notice details and hints that may have gone unnoticed, which facilitates finding a solution.
Intermittent conscious work	Smith and Dodds, 1999; Seifert et al., 1994	Incubation period as an attention switcher by intermittently thinking about the problem while doing mundane activities. This enables problem solver to reach the solution faster as the consciousness occur and problem readdressed intermittently, as well as to forget about the brief moments of work, leaving only the final solution remembered.
Attention-withdrawal	Segal, 2004	Incubation period as a set shifter and helper to forget about misconceptions. This enable problem solver to forget about misleading ideas or strategies.
UTT Theory	Dijksterhuis and Nordgren, 2006	Unconscious thought enables problem solvers to unconsciously process complex information while conscious attention is directed elsewhere. This process allows for the integration and weighting of relevant information over time, resulting in intuitive insights or decisions.
EII Theory	Helie and Sun, 2010	Incubation as a period that implicit processing or unconscious work captures memory retrieval and association. The theory integrates existing theories and suggesting that incubation can help in various ways, such as forgetting misleading strategies, allowing time for the assimilation of clues, eliminating blocks.
Fatigue dissipation / Recovery from fatigue	Smith, 2011	Incubation as a rest and refresh period. This enables problem solver to move away from very demanding preparation process and approach again in a renewed perspective.

Christensen and Schunn (2005) address theories of incubation under two categories: autonomous and interactive theories. Theories that are approached under autonomous incubation require phenomena to occur relying on the period of time (e.g. selective forgetting by Simon, 1966; blind variation, and selective retention model by Campbell, 1960). Theories belonging to the group of interactive incubation approach incubation to occur under the influence of external information or environmental cues (e.g. Opportunistic Assimilation by Seiffert et al., 1995 and Smith and Dodds, 1999).

Conscious and unconscious work hypotheses focus on the relationship between this period and the problem. The former proposes that the incubation effect is seen only if the problem solver intermittently thinks about the problem while attaining mundane activities. This, as a result, provides more time for one to think about the problem. The results of Gilhooly et al.'s (2012) study disaffirms the effect of the intermittent conscious work hypothesis since they cannot find any significant difference in the performance.

Table 2.7 Categorization of the theories of incubation by Christensen and Schunn (2005, p. 71)

	Autonomous	Interactive
Beneficial	Unconscious idea generation (e.g., Wallas, 1926)	Facilitating cues (e.g., Seifert et al., 1995; Langley et al., 1988)
Temporary detrimental	Fixation-forgetting (e.g., the returning-act hypothesis, Segal, 2004); fatigue dissipation (e.g., Woodworth et al., 1954)	Fixation-forgetting w/contextual shifting (e.g., Smith, 1995a)

The unconscious work hypothesis proposes that the incubation effect occurs when the problem solver leaves the problem behind; the brain continues to work on the problem unconsciously, which results in a solution emerging into conscious awareness. Several studies support that the process of unconscious thinking increases the level of creativity of the outputs (Dijksterhuis and Meurs, 2006; Gilhooly et al., 2013, Helie and Sun, 2013).

The theory of fatigue dissipation or recovery from fatigue proposes that the incubation period provides individuals time to relieve fatigue and get refreshed to solve the problem (Smith, 2011; Christensen, 2020). This is also because explicit processes require problem solvers to use attentional resources, which is an exertion-demanding process in contrast to effortless and relaxing implicit processes (Helie and Sun, 2013).

The selective forgetting hypothesis advocates that nodes of irrelevant information get inactivated to facilitate problem-solving during the incubation period (Simon, 1966; Smith and Blankenship, 1991). According to their advocators, forgetting irrelevant information makes relevant information relatively more accessible (Smith and Blankenship, 1989). This hypothesis is also named fixation-forgetting, selective forgetting, or problem-space forgetting by different researchers, but all of them are focused on the assumption that suppression of irrelevant concepts helps individuals to find solutions more easily and overcome fixation. In the process of overcoming fixation, problem solvers forget the mental sets, false strategies, and assumptions that prevent them from progressing on the potential solutions and enable them to start fresh (Gilhooly, Georgiou, and Devery, 2013). Similar to these, the attention-withdrawal theory argues that an incubation period works as a set shifter and helps to forget about previous misconceptions (Segal, 2004). However, in their empirical study, Sio and Rudovicz (2007) find no evidence to support the selective-forgetting hypothesis.

Opportunistic assimilation theory advocates that when unresolved problems are set aside, they are encoded in the long-term memory. When the problem solver encounters environmental cues, unnoticed details or hints might be noticed and facilitate a solution (Seifert et al., 1994; Smith and Dodds, 1999). During the iterative nature of problem-solving, with the aid of temporary results from the previous iteration kept in memory, a newly encountered environmental cue might help the problem solver reach a solution (Helie and Sun, 2013). In their study investigating the incubation effect on analogical problem-solving, Christensen and Schunn (2005) showed that participants were able to solve problems more effectively after incubation when they encountered environmental cues relevant to their unsolved problems. Their study provides empirical support for the OA theory, suggesting that the incubation effect can arise through spontaneous access to relevant information in the environment, thus "preparing the mind" for creative insight.

The spreading-activation hypothesis proposes that solutions are generated by integrating diverse information stored in long-term memory by activation of relevant networks during an incubation period (Yaniv, and Meyer, 1987; Smith, 1995). A more recent study by Sio and Rudovicz (2007) provides empirical support for this hypothesis and presents that spreading activation takes place and makes participants sentient to the relevant concepts during this period. Similar to this, the low cortical arousal theory by Martindale (1990) holds the view that defocused attention during an incubation period stimulates the construction of remote associations, which can only be achieved by defocused attention. Christensen (2020) explains the process: "Setting the problem aside, therefore, increases the chances of creative discovery through lowered arousal levels, leading to defocused attention, which allows for remote associations (p. 644)." This is also explained by the continuous search and retrieval during the incubation phase, which leads to a space of associations. Therefore, as the duration of incubation increases, the likelihood of retrieving remote associations increases as well (Helie and Sun, 2013).

Similarly, Remote Associates by Mednick (1964) proposes that creativity arises from the formation of new and useful associations between ideas or concepts that are not immediately related, and incubation plays a key role in allowing the mind to make these connections without focused, conscious effort on the problem. He suggests that unconscious processing plays a role in overcoming initial blocks during incubation. He also demonstrated that associative priming, in which participants are exposed to words or concepts related to the problem, can enhance the incubation process, even though the individual is not consciously working on the problem. When participants return to the problem after incubation, these primed associations are more likely to lead them to a solution.

A recent theory, the Explicit-Implicit Interaction (EII) model developed by Helie and Sun (2010; 2013), builds upon Wallas' stages of the creative process. While aligning with many existing theories, the EII model offers a more detailed and nuanced view of the cognitive mechanisms involved. According to EII (as covered in 2.1.3), the creative process can be investigated as the different levels of involvement between and interaction of implicit and explicit processes. Their critique is that the existing theories do not have a process-wise decomposition and enough detail. In their theory, they propose a decomposition in the creative process with greater detail which eventually enabled them to test it with computational models. It advocates that incubation relies heavily on implicit processing where the need for attentional resources is lower and associative processing is taking place.

There are some studies that question the existence of the incubation effect. For instance, in their attempt to replicate Dreistadt's (1969) study on six incubation mechanisms (free incubation, demanding cognitive work, active review, set breaking, stress reduction, and prominent visual analogies), Olton and Johnson (1976) found no evidence of an incubation effect, contrary to previous findings. Segal (2004) also argues that nothing significant occurs during incubation, proposing the attention-withdrawal theory, which suggests that the primary function of a break is to momentarily shift attention away from the problem, allowing individuals to return with a fresh perspective and reorganized assumptions. Similarly, Cardoso and Badke-Schaub (2009) found no significant difference between incubation and non-incubation conditions in their study on design fixation, where participants encountered pictorial and written representations in the early design phase. More recently, Campbell (2021) also reported no significant effect of incubation on creative performance. The mixed results across studies may be attributed to methodological differences, such as variations in problem type, incubation duration, and domain-specific factors.

2.3.2 Cognitive Backgrounds of Incubation

During problem-solving, different types of thinking are processed. Thinking is a covert and non-observable but inferable cognitive behavior in which "ideas, images, mental representations, or other hypothetical elements of thought are experienced or manipulated (APA, n.d.)." The types of thinking involved in the problem-solving activity depend on the nature of the problem. The utilization of judgments, decision-making, informal reasoning, and inductive and deductive reasoning might occur according to the problem's nature (Taylor and Workman, 2021). As it is discussed in Section 2.2, Goel (2010) argues that the cognitive processes and computational mechanisms involved in well- and ill-structured problem-solving processes differ from each other; ill-structured problems require lateral transformations in which associative search for different ideas occur, well-structured problems produce rule-governed vertical transformations that are also possible to articulate as compared to processes underlying ill-structured problems.

Benedek (2018) suggests that, during the initial phase, at which the problem is defined, a strategy is developed to inform idea generation. This strategy follows the iterative involvement of retrieval of relevant concepts. After that, integration and simulation take place to create novel representations that are followed by the evaluation of ideas to decide which one meets the task better. He highlights that the problem definition and strategy stages occur for every complex problem-solving process; however, when an individual deals with a problem-solving process that leads to a creative product, retrieval, integration/mental stimulation, and evaluation processes occur (Benedek, 2018).

The process of retrieval involves a broad search of long-term memory and reorganization of the memory representations (Tan et al., 2015; Li et al., 2007). It can also be defined as the evolution of the initial idea from an unfocused and abstract state to a focused state. This process of becoming a focused idea is produced by continuous memory search, memory retrieval, and reflection (Gabora, 2002). To create associations, individuals try to find relevant ideas with the presented stimuli in their memory, and this act of search becomes widened in every iteration, which leads to producing unexplored associations and creative ideas. It seems that incubation is a facilitator to widen the search for the network of knowledge (Sio and Ormerod, 2009). In his pioneering book, Simon (1970, p. 54) defines the relationship between memory and problem-solving as follows: "Problem-solving is often described as a search through a vast maze of possibilities, a maze that describes the environment. Successful problem solving involves searching the maze selectively and reducing it to manageable proportions." He suggests that successful problem solvers employ selective trial-and-error searches, using heuristics like means-end analysis to manage and narrow the search space, effectively making the maze of possibilities more navigable and manageable. Within this process, he describes two mechanisms, familiarization and selective forgetting, which are accounting. Since immediate memory has a limited capacity for holding only a few symbols at once, complex structures are gradually built from smaller substructures. Once a substructure is learned and stored in long-term memory, it can be represented by a symbol in immediate memory. This symbol can be combined with other substructures. So that, large structures can be assembled without overwhelming immediate memory, as only a few symbols need to be held at any time. Through familiarization, or exposing the chunk of information over and over, the symbol can be recognized and stored. Selective forgetting is the process where short-term memory, particularly related to problem-solving goals, fades more quickly than long-term memory, which retains useful information about the environment. Short-term memory holds dynamic structures, such as the hierarchy of goals, or in Simon's words, the *goal tree*, which is used to guide problem-solving efforts. Over time, this structure tends to decay or be forgotten more quickly than long-term memory, which retains information about the problem environment, a.k.a *the blackboard*. As a result, when a person returns to a problem after a break, much of the goal tree may have been forgotten, but the information stored in long-term memory (the blackboard) remains. This can lead to the individual following a different approach to solving the problem, often leading to new insights or a solution that had previously eluded them.

In another study investigating the role of memory in creative ideation, it is highlighted that memory-creation mechanisms are the foundation of creative ideation (Benedek et al., 2023). The process consists of semantic and episodic memory, in which they explain the involvement as follows:

> "Creative ideas result from the interplay of top-down, controlled memory processes (for example, cued memory search) and bottom-up, associative memory processes (for example, spontaneous associations guided by memory structure), drawing information from semantic memory and episodic memory. Semantic memory holds general knowledge and is commonly represented as a network, where related concepts are linked. Creative ideas can result from new links between previously unrelated concepts being forged. Episodic memory holds personal experiences that are reconstructed when they are recalled (Benedek et al., 2023, p. 6)."

The MemiC framework's four stages of creative ideation are demonstrated through the alternate uses task (Figure 2.11), which challenges individuals to think of innovative uses for common objects like a car tire. Using the property strategy, individuals explore their long-term memory for items with similar characteristics (e.g., a swing, hat, or lampshade) and attempt to conceptualize these objects using a car tire. If an idea is judged to lack novelty (e.g., swing) or practicality (e.g., hat), the process of idea generation is repeated until a solution that is both novel and functional, meeting the criteria for creativity, is achieved.

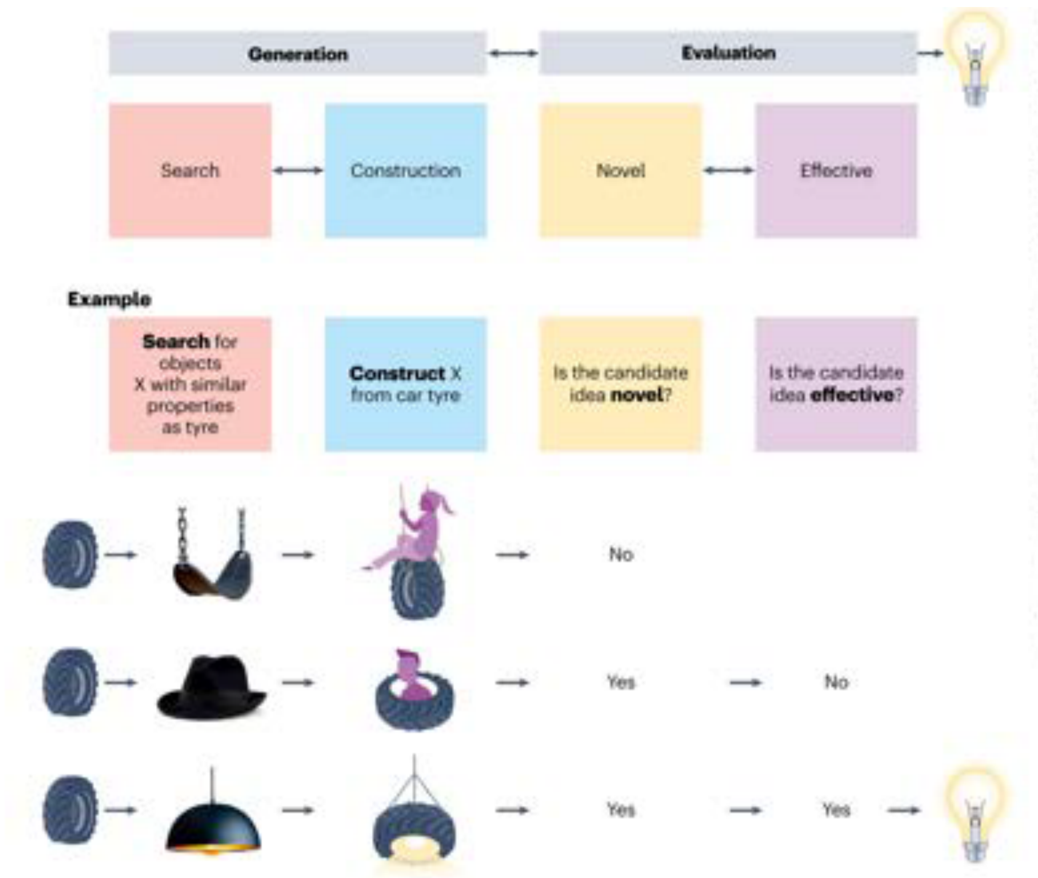

Figure 2.11 The MemiC Framework by Benedek et al. (2023, p. 6)

They offer an update on traditional theories of creativity by taking into account the significance of episodic and semantic memory for regulated retrieval during creative ideation. The study of Gilhooly (2007), in which they employ think-aloud protocol during Alternative Uses tasks, supports the involvement of episodic and semantic memory. While the initial responses of problem solvers are likely to be based on episodic memory or general personal memories, where the retrieval seems to be automatic and fast, the following responses tend to be slower and search in a semantically connected network.

Memory functions likely play an essential role during incubation by enabling the retrieval, organization, and reorganization of information relevant to creative problem-solving. While Benedek et al. (2023) and Gilhooly (2007) discuss the roles of semantic and episodic memory within the broader creative process, it can be assumed that these memory functions similarly support the incubation phase. Semantic memory, which organizes general knowledge in a network of related concepts, could facilitate the formation of novel connections between previously unrelated ideas, while episodic memory may provide unique personal and domain-related experiences. Together, these functions may allow for a dynamic mental exploration during incubation, potentially leading to breakthroughs once conscious focus resumes.

Another phenomenon and mechanism to address in incubation is conscious and unconscious thinking. Chalmers (1995) defines consciousness as "the subjective, inner life of the mind (p. 80)". Philosophers who approach consciousness as a unitary phenomenon draw a schema for categorizing mental states, which are raw feelings, propositions, and self-awareness (Rose, 2006). This brings us to an ongoing controversial debate on philosophy: how do the experiential qualities of things rise by the activity of the brain? Can particular functions explain it? Sobel and Li (2013) point out that while it may be possible to explain the awareness of the inner self and the outside world by explaining the behavioral and cognitive functions going on, there still is an unanswered question, which is to explain the accompanying experience on these performances. Although it is seen as *the hard problem of consciousness* (Chalmers, 1995), some contemporary philosophers approach consciousness as a solvable problem in light of new empirical advances. Like the concept of intelligence and creativity, which is the "emergent quality arising from the parallel functioning of complex systems", consciousness may not be found structurally or chemically in the brain but can be explained by considering it as an emergent property occurring eventually by the complex functioning in the brain (Sobel and Li, 2013, p. 376).

As addressed by different studies, unconscious thought has a place in implicit processes, which is seen during the incubation phase of a creative process. Sun (2002) suggests that the dichotomy of the conscious versus the unconscious is closely related to the dichotomy of implicit versus explicit. While explicit knowledge is available for consciousness, implicit knowledge is not. According to him, cognitive processes occur on two different levels with different mechanisms: “Implicit processes are inaccessible, “holistic,” and imprecise, while explicit processes are accessible and precise (p. 20)”. Although the mechanisms are diverse remarkably, they overlap and interact significantly, too. According to their theory named Unconscious-Thought Theory (UTT), Dijksterhuis and Nordgren (2006) present two modes of thought in human thinking, which are unconscious and conscious thought. As Banks (2021, p. 37) explains: “Unconscious thought occurs when the level of attention to a task falls below a threshold of conscious awareness but above a minimum threshold where no processing occurs at all.” On the other hand, conscious thought is cognitive or affective decision-related processes that occur while the decision-maker is consciously aware of the process (Dijksterhuis and Strick, 2016). Attention is the key that separates unconscious and conscious thought from each other: “Conscious thought is thought with attention; unconscious thought is thought without attention (or with attention directed elsewhere)” (Dijksterhuis and Nordgren, 2006, p. 96). During an unconscious thought, memory searching is more diffuse or divergent than conscious processes. Moreover, the unconscious has more resources available than the conscious, in which processing items are restricted within the scope of awareness (Dijksterhuis and Nordgren, 2006; Gao and Zeng, 2014). A neuroscientific study by Creswell et al. (2013) supports that decision-making mechanisms are facilitated by unconscious thought when the problem is complex. In their study, what they found is that unconscious thinkers made better decisions compared to conscious thinkers. Furthermore, Banks (2021) reveals three mechanisms of unconscious thought: automaticity, reward-based association, and spreading activation. Automaticity points out the automatic cognitive processes that are developed through practicing continuously until it becomes automatic: “Through repetition, a cognitive process can be completed increasingly quickly and with a low effort, which is an adaptive response to frequently encountered sequences of cognition” (p. 9). Reward-based association links the choices and their outcomes. Banks (2021) addresses studies that find evidence that people learn to associate certain decisions with either rewarding or punishing outcomes, and they can use these associations to make future decisions without being aware of the basis of their preferences. Spreading activation points out forming coherent representations by connecting relevant semantic networks: “Spreading activation assumes that semantic knowledge is stored in a network in which related concepts and facts are connected to each other through repeated associations that have been learned over time (Banks, 2021, p. 23)”.

In their empirical research investigating neural mechanisms behind unconscious thought, Creswell, Bursley and Satpute (2013) reported that unconscious processing enhances decision-making by allowing one to process previously encoded information when a decision is complex. Their study showed that, even though one is given a distractor task, the brain areas responsible for encoding decision information keep processing the main task without conscious awareness. These areas are the left intermediate visual cortex and right dorsolateral PFC. The results of their study are complemented by Creswell’s (2013) study of unconscious thought and decision-making. He reported the same neural regions as responsible for unconscious thinking during the distractor task. Furthermore, he reported that it is a predictor of decision quality.

In a study that set out to discuss the theoretical framework of creativity as a blind-variation and selective-retention (BVSR) process, building on Campbell's ideas from 1960, Simonton (2010) reported two cognitive processes to reinforce the blindness of the implicit search. The first one involves the activation of associative elements that can follow multiple directions from any initial stimulus, producing remote, rare, or divergent associations. The second one, which is more linked to incubation, describes a state of defocused attention where reduced latent inhibition allows extraneous stimuli to influence associative processes. In their study of the relationship between latent inhibition and creative achievement, Carson, Higgins and Peterson (2003) also found a significant effect of a higher creativity level of the person with the reduction in latent inhibition.

A phenomenon that shares similarities with incubation in terms of unconscious processing is the Tip-of-Tongue (TOT) phenomenon. It is the state when one is sure that she knows the word and is quite close to saying it but cannot recall it. It is remembered suddenly, like a moment of insight, while attaining different works with the help of unconscious processing in parallel (Olton, 1979; Christensen, 2005). However, the major difference between TOT and incubation is that while during incubation, the person generates something new with unknown qualities, during TOT, the person recalls already encoded information in the past. The common mechanism is that leads to reaching the right connection in a network of semantically connected nodes (Sobel and Li, 2013).

Another phenomenon that shares similarities with incubation in problem-solving is mind wandering, where attention unintentionally shifts from a goal task to unrelated internal thoughts. Mind wandering facilitates spontaneous mental exploration, which can lead to insights (Uzzaman and Joordens, 2011). This state activates the brain's default mode network (DMN), supporting unconscious processing that fosters remote associations and novel ideas—mechanisms also beneficial during incubation. The major difference from incubation is that, while mind wandering is an unintentional process, incubation is a purposeful break intended to allow for unconscious problem-solving. Nonetheless, both processes aid cognitive restructuring by reducing fixation on unproductive strategies, opening the way for new solutions to surface (Sio and Ormerod, 2015).

The EII theory explains the interaction between implicit and explicit processes (Figure 2.13). Since people are responding to verbal instructions in the preparation phase, creating representations of the problem and establishing goals must be explicit. After many repetitions, the knowledge that was first acquired explicitly often gets absorbed and re-coded into an implicit form, which is top-down assimilation. Incubation mostly relies on implicit processing. The implicit process during the incubation is then explicitated, insight is acquired through bottom-up processing, and the knowledge becomes available for a verbal report (Helie and Sun, 2010; Helie, 2013).

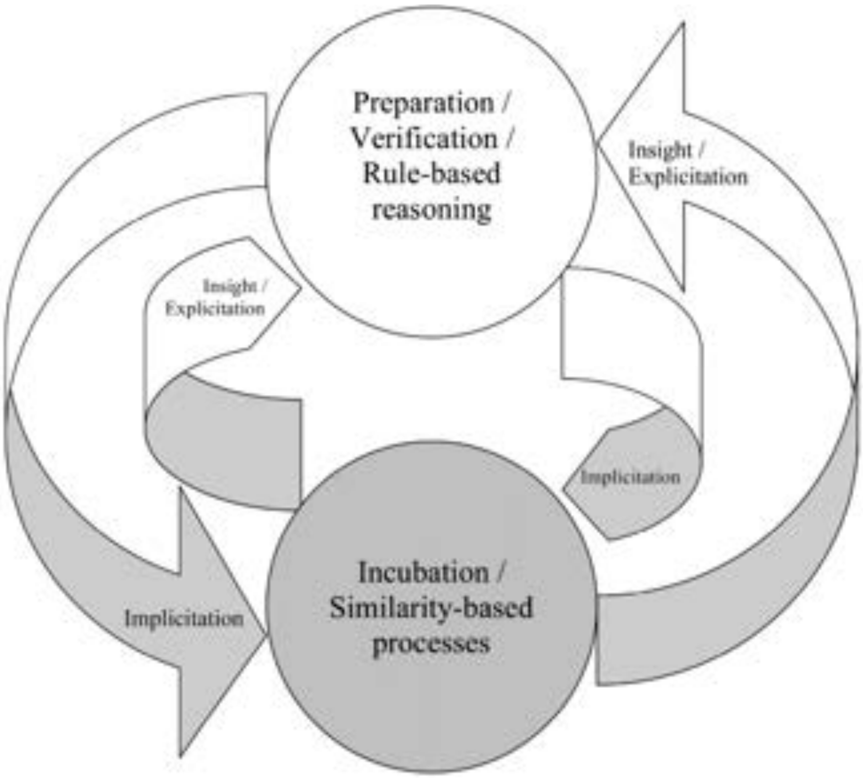

Figure 2.12 The Explicit-Implicit Interaction Theory explains the interaction between implicit and explicit processes (Helie, 2013, p. 6)

Following the EII theory, Helie (2013) developed the neuro-EII Theory, which maps different brain regions involving the four phases of the creative process. While the lateral prefrontal cortex and hippocampus are activated in the explicit processes (preparation and verification), the parahippocampal gyrus is involved in the incubation phase, and the anterior cingulate cortex is involved during insight. He further emphasizes the possible involvement of the DMN.

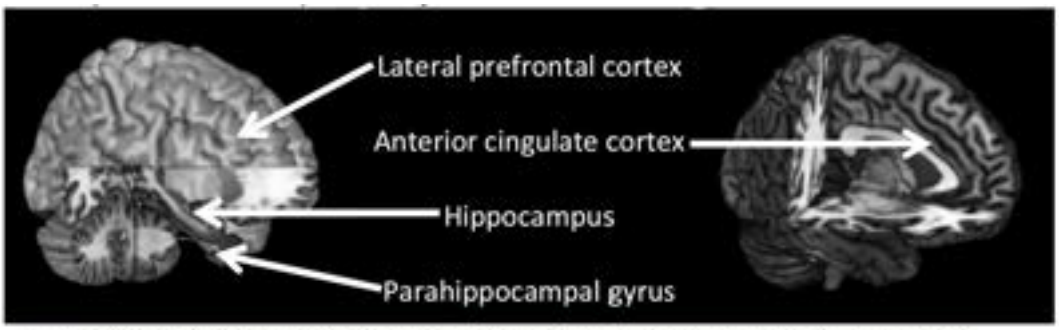

Figure 2.13 Brain regions involved in the creative process by Helie (2013, p. 6).

Another model that explains the neurocognitive backgrounds of the creative process is Benedek’s (2018) RISE model. According to this model, while the retrieval of ideas is linked with the ventrolateral prefrontal cortex (VLPFC), integration and simulation are linked to the inferior parietal cortex (IPC), and evaluation links to dorsal parts of the prefrontal cortex (dPFC).

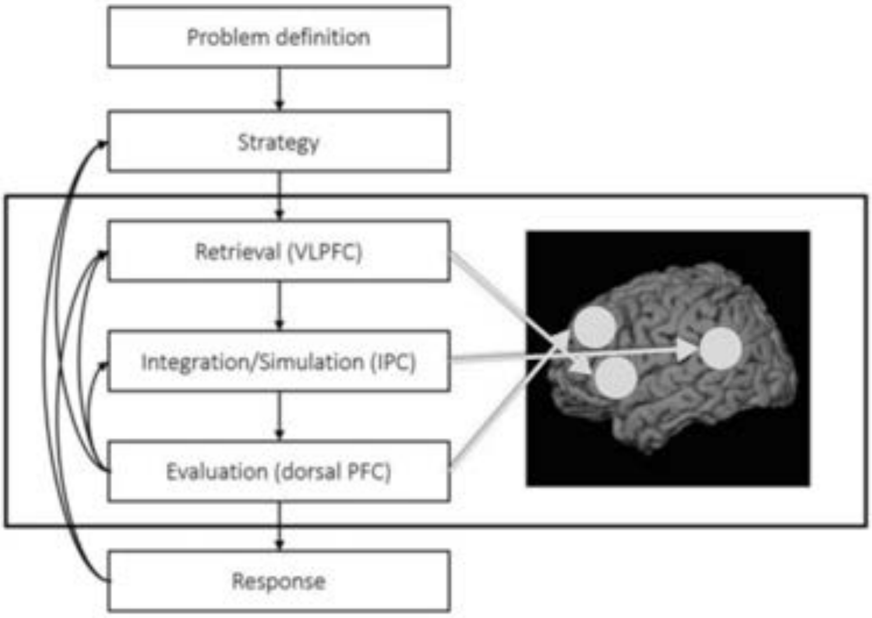

Figure 2.14 Benedek's RISE model (2018, p. 38)

Another prominent function discussed in the literature is hemispheric asymmetry, which has been widely examined in studies of the creative process (Martindale et al.,1984; Schwab et al., 2014; Fink and Benedek 2013). Several lines of evidence suggest that problem-solving engages the brain's hemispheres in distinct ways: the left hemisphere, focused on language processing, strongly activates specific concepts, while the right hemisphere, associated with imagery, broadly activates a wider array of concepts. Just before an insight solution, a neural burst is observed from the right hemisphere to the left, leading to a unified problem representation that facilitates the solution (Bowden et al., 2005). Moreover, the resolution of semantic processing differs between hemispheres. While the left hemisphere narrowly focuses on semantic fields and selects precise and contextually relevant concepts, the right hemisphere operates at a lower resolution in processing, using broad semantic fields with distantly related concepts (Bowden and Jung-Beeman, 2003). In their electrophysiological study employing divergent thinking problems and aiming to understand the role of unconsciousness in creative problem-solving, Gao and Zhang (2014) find the role of right parietal, parahippocampal, and temporal areas in semantic activation of unconscious cues, forming new associations and transforming mental representations.

The EEG spectrum is commonly divided into distinct frequency bands (Figure 2.16), each associated with different cognitive and physiological states (Tiwari et al., 2021). Delta waves (1–4 Hz) are prominent in deep sleep, theta waves (4–8 Hz) are linked to drowsiness and creative problem-solving, alpha waves (8–12 Hz) are associated with relaxation and attentional processes, beta waves (12–30 Hz) indicate active thinking and concentration, and gamma waves (above 30 Hz) are connected to higher-level cognitive functioning (Tiwari et al., 2021). The alpha band, in particular, has been extensively studied due to its link with internally focused tasks and creative thinking. Increased alpha power, especially in the right parietal lobe, supports internally directed cognition, often shielding cognitive tasks from external distractions. According to Benedek (2018), attentional focus and the regulation of memory retrieval help explain the connection between alpha activity and creativity. In their study investigating the functional role of alpha power in memory and divergent thinking tasks, Benedek et al. (2014) reported that alpha synchronization in the right parietal lobe is indicative of internally directed cognition. This synchronization has been interpreted as a protective mechanism, shielding cognitive tasks from distracting sensory stimuli during memory retrieval and the visual manipulation of existing knowledge.

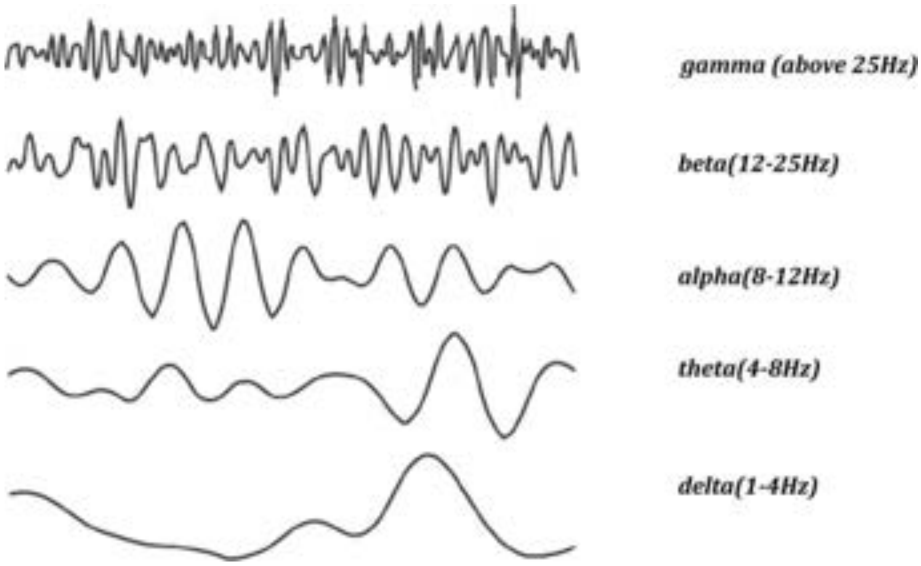

Figure 2.15 Frequency bands of EEG data (Tiwari et al., 2021, p. 4826)

It is further noted that, at the neural level, studies using EEG alpha frequency activity and functional MRI indicate that visual input is actively suppressed when individuals engage in divergent thinking tasks requiring high levels of internal processing. EEG alpha activity is thought to represent a top-down mechanism that reduces external visual information processing (Benedek et al., 2014; Walcher, Kölner, and Benedek, 2017). Additionally, the right inferior parietal cortex has been identified as playing a key role in down-regulating visual processing when tasks demand intense internal attention (Benedek et al., 2016; Walcher et al., 2017).

2.3.3 Experimental Studies on Incubation

A typical experimental setting for testing the incubation effect employs two conditions, one of which contains an interrupted process and the other using a continuous problem-solving process. In the interrupted process, the participants are either given a problem with a varied degree of difficulty to work on (filled), or no problem is given (unfilled). Finally, participants return to the problem space and attempt to solve the problem (Christensen, 2005). Most recent studies design their experimental settings where participants are either involved in another problem-solving period occurring in between the process or a continuous process in order to support the spreading activation hypothesis or selective forgetting hypothesis.

The very first experimental settings that compare continuous versus interrupted processes indicate that the creativity results increase during an interrupted process (Fulgosi and Guilford,1968, 1972; Mednick, Mednick, and Mednick,1964; Murray and Denny, 1969; cited in Sio and Rudovicz, 2007). However, they lack evidence on the source of the incubation effect, meaning whether the results were affected by decreasing mental fatigue or concealed consciousness of participants working on the problem. Later on, many reports (Seifert et al., 1995; Hernandez, Shah, and Smith, 2010; Tsenn et al., 2014; Sio and Ormerod, 2009) indicate that giving a break during the problem-solving process reveals better performance as compared to the continuous problem-solving process.

Hernandez, Shah, and Smith (2010) cover incubation as one of the ideation components during their series of design and lab experiments. They give 2 days of incubation with no specific instructions for design experiments, while 10 minutes for lab experiments. The results show the overall positive effect of incubation on four metrics (novelty, variety, quantity, and quality), though less on quality, in both conditions.

In their study of comparison of delayed versus immediate incubation, Gilhooly et al. (2012) show that the effects are diverse between the two conditions. While in immediate incubation, a break is given right after the problem is presented, in delayed incubation, a preparation time is given before an interpolation. Both are followed by a post-incubation period in which the participants continue to work on the target task. Their results show an increased performance after immediate incubation. One interpretation is that delayed incubation, where conscious work occurs before the incubation period, allows for the development of strong mental sets. This delayed incubation could involve both beneficial forgetting and unconscious processing. However, this approach may be less effective than immediate incubation, where these sets are minimal or nonexistent, allowing unconscious processing to occur without the need to overcome prior thought patterns (Gilhooly et al., 2012).

In Mednick's (1964) study, subjects who received specific associative priming performed better on remote-associate tasks, showing that priming cues facilitated connections that aided problem-solving when they later revisited the tasks. Further, a meta-analysis by Sio and Ormerod (2009) supports the positive effect of cues in the incubation period.

Building on the studies on incubation effects, Sio and Ormerod (2009) identify five modulators for discriminating conscious-work and unconscious-work hypotheses as well as for recognizing underlying mechanisms such as recovery from fatigue and forgetting. These are the nature of the problem, length of the preparation period, type of task during the incubation period, length of the incubation period, and presence of solution-relevant cues. According to Christensen (2005), the modulators can be expanded by taking the pre-incubation time, post-incubation time, information given to participants beforehand, and the presence of cues into account.

The nature of the problem is highly dependent on the research domain. It could be open or closed, ill-defined or well-defined, simple or complex (Christensen, 2005). The majority of studies adopt the Remote Associates Test (RAT) by Mednick (1968) which makes use of verbal materials to create remote associations. The nature of other problems is linguistic and visual, and the goals are well-defined in common.

What is regarded as the type of task during the incubation process is that the incubation process can be either filled with a task different than the problem that is studied or unfilled where no planned tasks take place. Previous studies demonstrate that low cognitive demanding tasks are more beneficial than adapting high cognitive demanding tasks during the incubation period.

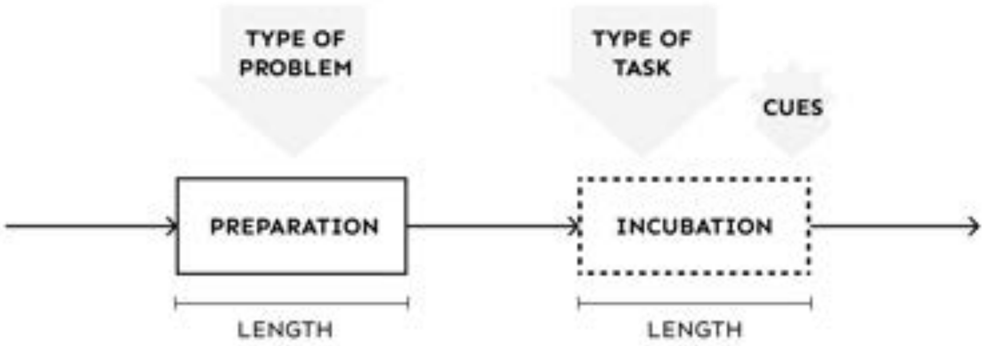

Figure 2.16 Five contributors to the incubation effect, based on Sio and Ormerod (2009)

The duration of the pre-incubation and incubation period is another contributor. The study of Penney et al. (2004) found that shorter incubation periods (15 to 30 minutes) were most effective, as they helped reduce fixation on unproductive ideas and encouraged fresh perspectives, leading to more new solutions. In contrast, longer breaks, 3 hours or more, were less beneficial, likely because the problem and its cues faded from memory, making spontaneous retrieval and new solutions less likely. For some complex tasks, extended incubation of up to three and a half hours has also been beneficial, as shown in Silveira's (1971, as cited in Dodds, Ward, and Smith, 2004) research. In her experiments, longer breaks allowed participants to overcome mental blocks effectively, but excessive intervals, such as over a day, tended to diminish benefits, possibly due to fading of problem-related cues. In their study investigating the effect of unconscious processing on creative problem-solving, in which Gao and Zhang (2014) employ conscious cue, no cue, and unconscious cue conditions, their results show that participants solved fewer problems in unconscious cue condition as compared to conscious cue condition. This is because the activation from a source diminishes as it spreads outward and paths of spreading activation can intersect if they originate from different sources, and an intersection becomes consciously detectable only when its activation level hits a certain threshold. As more concepts are activated, each individual concept's activation weakens. At the same time, the longer a concept is processed, the further its activation extends, creating more intersections. Consequently, although unconscious activation is more widely distributed, it often lowers the activation level at each intersection, making it less likely for any intersection to be consciously recognized. Therefore, time is needed to reach a stronger activation that eventually extends the threshold and allows transferring it to the conscious state. On the other hand, the study of Christensen and Schunn (2005) highlighted the importance of the time spent on encoding the problem before encountering an impasse, which is critical in predicting spontaneous access and retrieval success. The deeper engagement with the problem initially, the higher the chances of later retrieval when an environmental cue is encountered.

2.4 Incubation in the Design Process

If we represent the design process and creative process sequentially based on the models in the literature, this kind of representation enables us to compare and relate their sub-phases. Although in the real world, it might not be possible to simplify the process into linearly followed steps, it is necessary to do so to apply experimental protocols and gain an understanding of the cause-and-effect relationship.

The figure clearly illustrates that, when represented sequentially, the similarities between creative problem-solving models and design models become more apparent. For instance, the development phase in Double Diamond aligns with the illumination phase in Wallas' model, the response phase in Amabile's model, and the idea generation and idea combination phases in Sawyer's model. Notably, two of the creativity models explicitly include incubation as a distinct process occurring before idea generation, whereas the Double Diamond model and Amabile's creativity model omit this phase. Given the critical role of a sufficiently long preparation phase in facilitating the incubation effect, it is recommended to incorporate an incubation period after the problem space has been explored and the problem redefined. This adjustment aims to promote spreading activation and enhance the creativity of the resulting ideas.

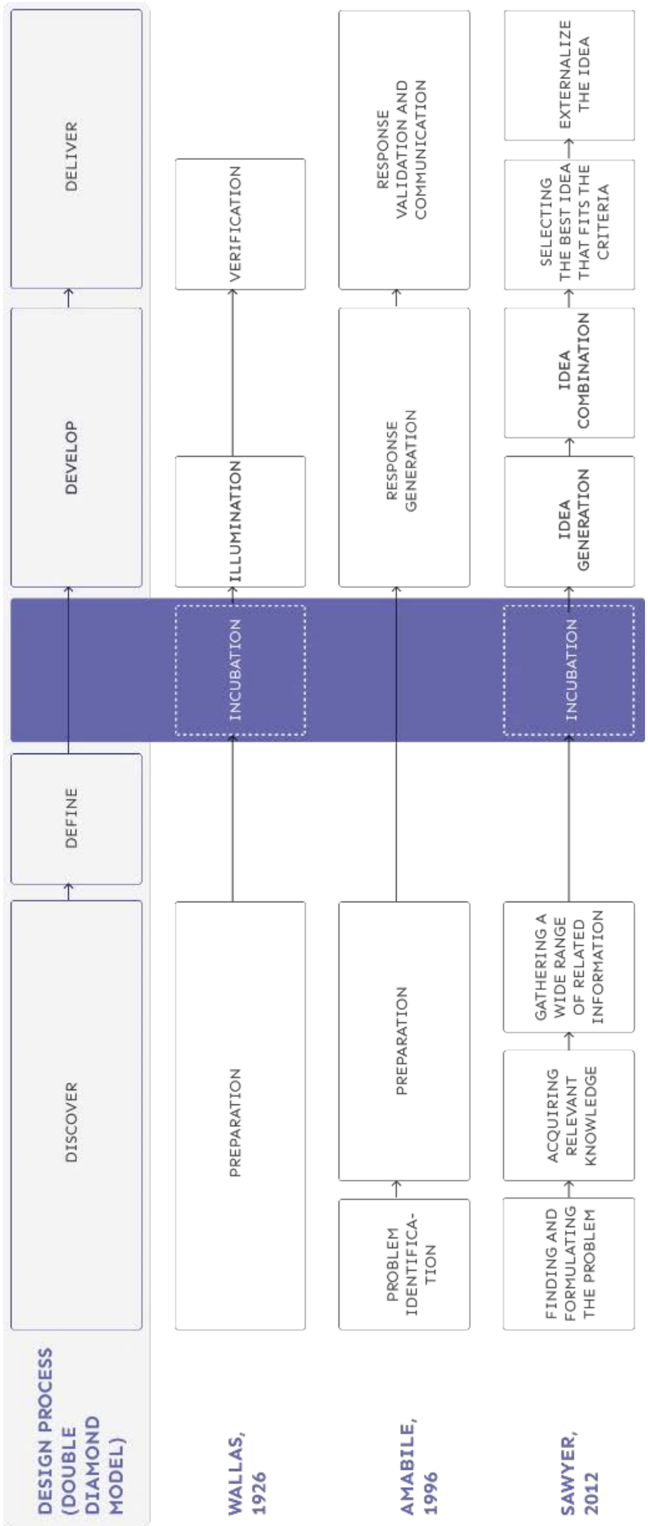

Figure 2.17 The sequential representations of the Double Diamond design process model in reference to creative process models, highlighting the place of incubation

In their study of idea generation methods, Kirjavainen and Hölttä (2020) find incubation as one of the idea sources in the design process, meaning that it triggers cognition to produce new ideas. However, they highlight that it is an underexploited mechanism and appeared only in four idea generation methods, although the effects are found to be beneficial (Kirjavainen and Hölttä, 2020). Furthermore, as discussed by Hernandez, Shah, and Smith (2010), the incubation period can be added to any idea generation method's procedure since it works as a stimulator of connecting new associations. A study by Tsenn et al. (2014) examined the effect of incubation and time on concept generation in engineering design and revealed that incubation helped novice designers break fixation, providing more variety and less copying in the solutions.

In design, incubation is closely examined for its role in overcoming fixation, which is a common challenge where designers struggle to move beyond initial ideas or existing solutions. Fixation can inhibit the flow of concept generation, often restraining designers to familiar concepts and limiting creative output. By stepping away from a problem, incubation allows subconscious processing, which can lead to new associations and reduce fixation. Thus, it serves as a valuable phase within the creative process that encourages fresh perspectives. In the following section, fixation in design is explored further, particularly for how incubation has been integrated into design methods as a mechanism to mitigate its effects and enhance creativity.

2.4.1 Fixation in Design

Fixation refers to a barrier that hinders progress in problem-solving and prevents the completion of a problem (Jannson and Smith, 1991; Gonçalves, 2016). In design studies, it can be defined as an unintentional or automatic use of ideas or components from examples without thinking about whether they are appropriate for the problem at hand (Purcell and Gero, 1996; Beda and Smith, 2022). Design fixation is a well-studied topic in design research, yet there are ongoing discussions regarding the varying interpretations and applications of the term across different studies. (Youmans and Arciszewski, 2014; Gonçalves, 2016).

Youmans and Arciszewski (2014) draw attention to the broadness of the term and suggest three main forms of it based on the uses in the literature, which are unconscious adherence, conscious blocking, and intentional resistance. By unconscious adherence, they refer to encountering examples and being influenced by them without awareness. Adhering to the opinions of others or becoming distracted by other powerful memory targets or even other concepts that have already been formed throughout the thought process might cause fixation (Beda and Smith, 2022). The reason behind this phenomenon is closely related to how our brains work. The associative nature of memory retrieval enables access to more available information with a similar concept that might be recently encountered or frequently thought items (Martini, 2018). Also, the prior knowledge of similar problems has stronger and more direct connections with the current problem and, therefore, automatically receives a great amount of activation (Sio, Kotovsky, and Cagan, 2017). The priming effect, which shows that presenting one item will accelerate reactions to a related item, is major evidence supporting this activation process (Ratcliff and McKoon, 1988). The unconscious occurrence of this activation network makes it harder to overcome.

When designers become aware of their fixation on an idea, conscious blocking might occur (Youmans and Arciszewski, 2014). It often stems from a designer's previous experiences, hindering their ability to generate novel ideas or explore alternative pathways beyond those they have previously followed or are familiar with. They suggest taking breaks to incubate different potential solutions. Smith et al. (1993) demonstrated that past experiences can restrict the generation of novel ideas because individuals conform to familiar patterns. In their experiments, even though during the condition that the subjects were told to generate different ideas from that presented, the conformity effect could not be diminished, and subjects came up with solutions similar to the examples shown.

Intentional resistance refers to the conscious preference for what has already been accepted as a successful solution to a novel solution (Youmans and Arciszewski, 2014). In that case, designers choose to follow the older and proven system, aiming to reduce the risk of coming up with a new but not working solution. Design resistance generally prevails over the generation of novel and innovative ideas. This interference generally occurs without awareness and might perform as a mental block by hindering the retrieval of more appropriate answers. An explanation for this unconscious fixation is that information is stored in human associative memory systems through associative networks of related concepts in a way that increases the likelihood of retrieving recently activated notions (Youmans 2011; Youmans and Arciszewski, 2014).

For the sake of creativity, a crucial query arises: How might designers effectively address or counteract fixation tendencies within the creative process? Smith and Linsey (2011) suggest three routes to overcome fixation: forgetting fixation, problem redefinition, and using clues in the environment to stimulate new ideas. Putting the fixated idea out of the mind by following the various cognitive mechanisms and then redefining the problem corresponds to forgetting fixation. Yet, this mitigation is only available if a designer is already aware of their fixation. Regarding problem redefinition, they suggest that the cause of fixation relies on the way that the problem is defined in the first place, which might be too distinct in approaching the problem. By environmental clues, they suggest that the stimuli in the environment act as relevant clues that inform the design process. They suggest that designers look for environmental change to overcome fixation by providing clues that have a high probability of stimulating good solutions. The effect of the environment either acts as a contributor to the inventiveness or a cause for fixation. The qualities of the sources within the environment are presented as mitigation by other researchers as well (Runco, 2011; Youmans and Arciszewski, 2014).

In his study of understanding the effects of instructions on fixation, Martini (2018) found that when the instructed feature has a neutral relationship with the design, subjects are more likely to fixate on it because they are not aware of the occurrence of fixation. In comparison, while irrelevant items are the ones that subjects are least likely to become fixated on because they draw the greatest attention, the relevant items have a potential for subjects to become conceptually fixated on, but not as much as the neutral ones. Thus far, he suggests a two-pass approach for eliminating the fixation effect caused by instructions. The suggestion for a designer is to get exposed to earlier designs, which will probably result in the blocking of relevant things that are interacted with consciously. Then, it is advised to conduct a second evaluation to find neutral aspects of a particular product or design to catch the unconscious fixated elements (Martini, 2018).

Another suggestion is to introduce ideation methods into the process to stimulate lateral thinking and create a new direction in search (de Bono, 1970; Youmans and Arciszewski, 2014). In their study, Youmans and Arciszewski (2014) examine four idea generation methods and their effects on different orders of design fixation. What they point out by the order of fixation is that the level of knowledge resource that is being used in the design process might trigger different orders of fixation. If a designer uses their knowledge coming from past experiences, it is called first-order knowledge. If they refer to knowledge from the area, such as mechanical engineering knowledge, it is called second-order. Third- and fourth-order knowledge refers to information that is more distantly related. Following this, they suggest that, when a designer relies on first-order knowledge, morphological analysis might help extend the information area to overcome fixation. They further suggest introducing brainstorming for second-order, TRIZ for third-order, and Synectics for fourth-order fixation.

Another way to mitigate fixation is to make way for forgetting. A growing body of evidence suggests that incubation has a positive effect on inducing the fixation effect (Shah et al., 2003; Kohn and Smith, 2009; Tsenn et al., 2014; Sio, Kotovsky, and Cagan, 2017). An incubation period functions as an introduction to new combinations through the construction of new associations, which enables the designer to eliminate the connection between primer concepts.

2.4.2 Insight

Insight can be defined as a sudden recognition of a solution to a problem after when the problem appears to be difficult to solve and there is no obvious way out (Gick and Lockhart, 1995; Banks, 2021). A discontinuity in the problem-solving procedure and the mechanism of restructuring during that time is the distinguishing factor between insight and non-insight problems (Weisberg, 1995). It is suggested that to achieve instant insight, one should consider restructuring the problem during an impasse (Ohlsson, 1992; Simon, 1995; Gilhooly and Murphy, 2005).

Smith (1995) distinguishes between insight, insight experience, and insight problems. While he defines insight as an understanding of its mechanisms, insight experience is the sudden and unexpected occurrence of an idea, the so-called Aha! moment, and insight problems are defined as problems more likely to be solved via insight experience. Insight experience is thought to be the interaction of unconscious thought and conscious thought. Banks (2021) gives an example of the Aha! moment of insight as the moment of shift or moment of enlightenment, when the unconscious process becomes conscious. This transition is also seen as one of the properties of insight. Insight cannot be defined as another step in the problem-solving process; rather, it is a transition from a state of not knowing to a *state of knowing* (Helie and Sun, 2010). However, insight cannot be defined as a single process; it is the result of multiple interacting processes (Bowden and Jung-Beeman, 2007).

The problem solver's attitude or experience is another significant factor that needs to be considered regarding insight. An insight problem-solving process is driven by the problem solver's experience of an incomprehensive period followed by a transition to a knowing state (Gick and Lockhart, 1995). Following this, Gick and Lockart (1995) suggest that while a problem can be an insight problem for one, it might be a non-insight problem for another since the representation of a problem is closely related to the problem solver's experience. Another study advocating that the problem solver has an effect on the insight problem-solving process approaches insightful solutions as creative ones that have a quality of novelty along with their appropriateness (Sternberg and Lubart, 1995). Therefore, together with the cognitive abilities, the attitude of seeking a novel idea is needed to have an insight experience. This is what the Investment Theory of Sternberg and Lubart advocates by constructing a metaphor for investing: creative individuals are able and willing to purchase low and sell high in the world of ideas, just like successful investors do in financial markets.

Insight problems are ill-defined problems in which the solution is not apparent in advance and requires a problem solver to restructure it in the process. Mayer (1995) makes a classification based on the qualities that insight problems have. He highlights that one focuses on the internal representation of the problem that guides one through the solution instead of directly focusing on the solution. Further, an insight problem is non-routine and has not been solved or encountered before. Lastly, one thinks productively rather than reproductively, meaning that the conventional solution procedures do not meet the novel requirements to solve insight problems. Similarly, Bowden and Jung-Beeman (2007) advocate that the problem solver must leave the traditional approaches behind to make this phenomenon happen.

In his research on the taxonomy of problems, Weisberg (1995) draws a schema for classification (Figure 2.18). According to his theory, to be able to say that the problem is an insight problem, the problem-solving procedure must go through particular stages. At almost every stage, if the problem does not satisfy the requirement, he suggests one to put the problem aside to enable cognitive mechanisms that allow the problem solver to restructure the problem. A critical approach to diversify insight problems from non-insight problems by Bowden et al. (2005) advocates that apart from employing precisely specified procedures to categorize problems as insight- or non-insight-problems, the operational definitions of insight ought to be applied separately to the problems at hand.

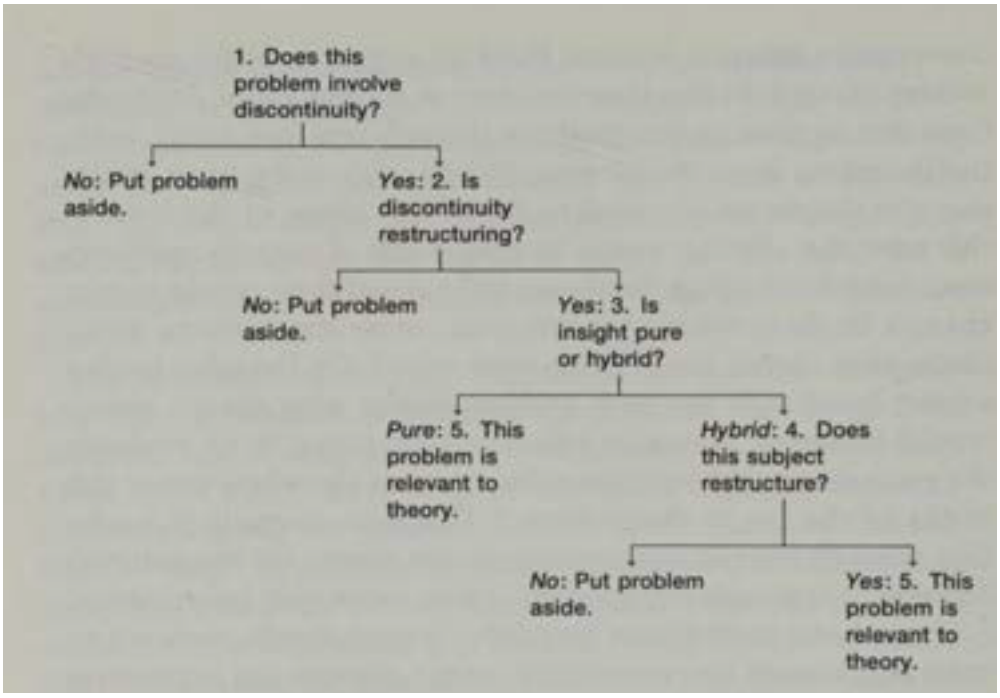

Figure 2.18 Weisberg's taxonomy of problem (1995, p. 168)

Contrary to previous studies, Beaty et al. (2014) have looked at the role of insight in creative achievements by employing RAT and self-reports in their series of experiments. However, they reported no effect of insight on creative achievements. They suggest that rather than unconsciousness, a controlled cognitive process is central to creativity. The important aspect of this study is that they ask problem solvers whether they solve the problem with insight. This means that insight is not assumed because the problem is an insight problem, but participants are asked about it. Still, it should be considered that RAT is seen as a convergent thinking task more than a divergent thinking task, therefore, it is meaningful to expect cognitive control over the problem-solving process.

In their study investigating the neural components of insight, Bowden and Jung-Beeman (2007) emphasize that insight arises as the result of complementing existing weak associations rather than creating new associations. Due to the limitations of neuroimaging methods that they adapt to their study, they employ anagrams and items from RAT, which can be solved within a short amount of time;

they are more straightforward and easier to measure. Their study reveals that the increased activity in the right hemisphere in insight solutions might be the indicator of restructuring the problem. A similar study investigating the neural components of insight by Rothmaler et al. (2017) examines intrinsic and extrinsic insight, in which the classification is made based on the trigger of insight experience, which can either be an external hint or an internal solution attempt. They found that the alpha power shows an increase before intrinsic insight occurs, which indicates raised internal attention. On the other hand, a decreased alpha power is examined during extrinsic insight, associating it with a more external focus of attention. Overall, their study sums up that there is a significant difference between intrinsic and extrinsic insight on a neurophysiological and behavioral level.

Another study investigating the neural components of insight by Bowden et al. (2005) argues the limitations of traditional research aspects in demystifying insight and proposes to supplement it with new paradigms such as cognitive neuroscience. They employ problems that can either be solved with or without insight, they use a large number of problems within the experiment and record brain activity via EEG. Their results show that while all types of problem-solving rely on a widely shared cortical network in the brain, different neurological and cognitive processes are involved in the rapid flash of insight. That is a sudden increase in alpha power in the right visual cortex, indicating a decrease in neural activity, enabling solvers to discover connections that were previously invisible to them. They conclude that, just before insight appears, problem solvers rapidly shift their effort to solve the problem, which enables them to connect solutions to problems with the emergence of consciousness.

Banks (2021) considers that the spreading activation occurring during an unconscious thought process, that is, incubation, contributes insight. When the activation held in a network of semantically connected nodes reaches a threshold, one can become aware of it. This process is also associated with the tip-of-tongue phenomenon, where one suddenly finds a word that they have already given up looking for (Sobel and Li, 2013). In another study searching the effect of incubation in insight problem solving, Segal (2004) designs a study to meet the optimal conditions for an incubation following a procedure in which a break is given just after the subject faces an impasse during the insight puzzle-solving process. His theoretical approach to incubation is based on the attention-withdrawal hypothesis, which suggests that the function of incubation is to direct the attention from the problem, thus diminishing the validity of the false assumption of the problem solver. According to the results of his study, higher performance is seen in break conditions compared to no-break conditions in a demanding problem-solving task, while the length of the break does not cause a significant difference.

2.5 Theoretical Framework

This study aims to explore the role of incubation in design creativity by examining three interrelated aspects (1) the incubation period and creative performance, (2) the creative potential and the cognitive functions during the incubation period, and (3) the creative potential and creative performance.

Given the importance of creativity in the design process, understanding its mechanisms is crucial for informing design practices. However, creativity should not be treated as a monolithic concept; instead, its components must be investigated individually. In this research, the incubation phase of creativity is the focal point. To reach a holistic understanding, this thesis adopts a framework that evaluates not only the process but also the person and the products involved.

To evaluate individual creativity, this study employs two self-reporting scales: one measuring creative motivation and the other evaluating cognitive processes associated with creativity. The former is grounded in the premise that a problem solver's motivation significantly plays a role in shaping the creativity of their outcomes. The latter measure is included because creative thinking skills and strategies affect the design process considerably. Together, these scales provide a holistic approach to one’s creative potential.

The process is examined using electroencephalography (EEG), a neuroimaging tool that records the brain's electrical activity, chosen for its capability to quantitatively analyze cognitive mechanisms underlying incubation and its availability in the university. EEG provides objective data on cognitive activity during the unfilled incubation period. In contrast to a normal resting state, spontaneous brain activity during incubation may show unique patterns of spectral power changes, reflecting specific cognitive processes. The differences observed between resting and incubation states may reveal how intrinsic brain activity supports cognitive mechanisms such as restructuring, memory retrieval, and idea generation during the incubation phase.

Regarding the evaluation of outputs, this research proposes using three of the four metrics outlined by Shah, Kulkarni, and Hernandez (2018)—quantity, variety, and novelty—to assess the level of creativity in products, recognizing that creativity in design impacts output quality in multiple ways. These metrics are particularly advantageous because they provide qualitative evaluations that can be converted into quantitative data, enabling comparisons between variables. This dual approach ensures a comprehensive assessment of creative outputs.

What is also taken into consideration is that studying creativity and incubation within design research requires selecting appropriate tasks representative of real design problems. Therefore, the problems given to participants during the experiment are curated delicately to reflect practical design scenarios.

Overall, the study hypothesizes that incorporating an incubation period between the problem definition and idea development phases can enhance the creativity of design outcomes. This is based on the premise that incubation facilitates a broader exploration of the knowledge network. Each time the problem is revisited, the search expands, and cognitive restructuring occurs. Given that effective design problem-solving demands extensive connections and a high degree of restructuring, the process appears to benefit significantly from this approach. This proposition is visualized in Figure 2.19, which presents the proposed design process model based on the Double Diamond design model.

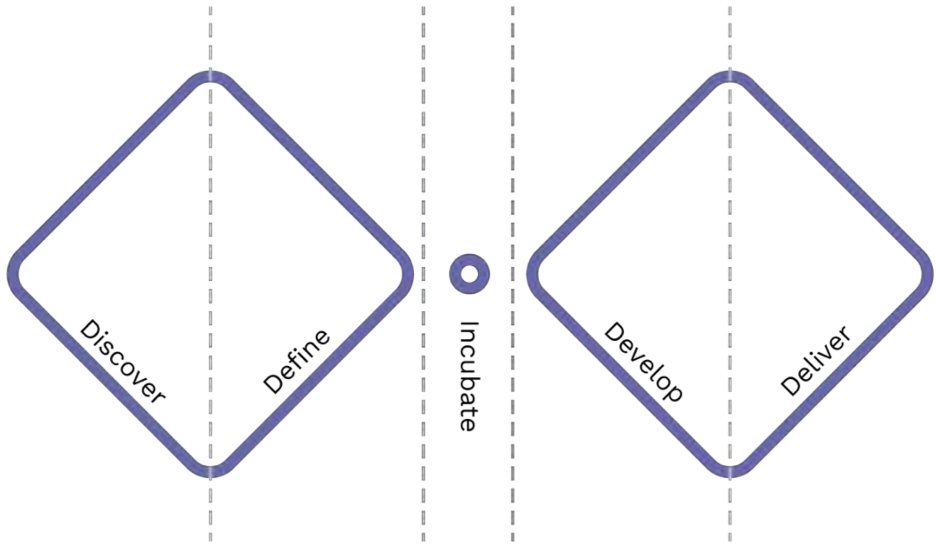

Figure 2.19 The proposed design process model within this thesis based on the Double Diamond design model

Given the multimodal nature of the design process, this research adopts a mixed-methods approach. This dual approach aligns with the broader goal of advancing design theory by integrating quantitative insights into design cognition with qualitative assessments of creative performance.

CHAPTER 3

METHODOLOGY

The methodological framework of this thesis is constructed based on the insights from the literature review and the aim of understanding the effect of an incubation period on creative performance and cognitive mechanisms.

This chapter outlines the research methodology in a structured manner. It begins by describing the research and sampling strategy. This is followed by the research design, in which the preparation period is explained in detail. Then progresses to discuss methods employed for data collection and data analysis methods. Finally, it presents the results, offering insights into the outcomes of the applied methodologies.

3.1 Multi-strategy Research Design

The research follows both a quantitative and qualitative strategy, using mixed methods. The typology of the multi-strategy (mixed methods) design in a study carries the characteristics of concurrent triangulation and nested design (Robson and McCartan, 2016). Concurrent triangulation design indicates the use of qualitative and quantitative methods separately, independently, and concurrently (Robson and McCartan, 2016). A comparison of outcomes is made to assess the convergence of the two methods for the concurrent triangulation design. The nested design refers to involving a secondary method within a study of the primary method. In this study, the quantitative data collection method is employed as the primary source of data and the qualitative data collection method is used as the secondary source of data and is benefited from during the explanation of the results.

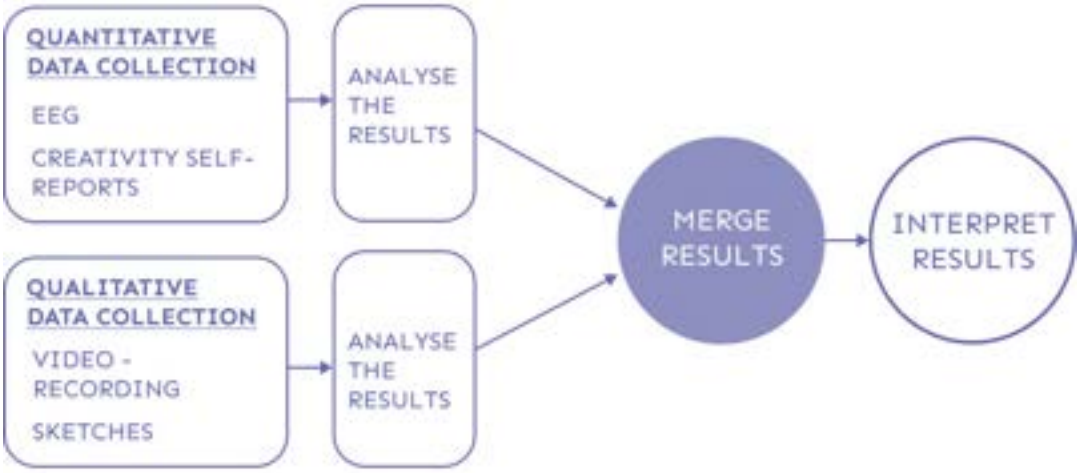

Figure 3.1 Research Strategy adapted from Creswell and Creswell (2018, p. 300)

The same sampling is used throughout the process. Data collection, analysis, and validation approaches are described in further sections. The research procedure diagram can be found in Appendix A.

3.2 Sampling Strategy

The sampling population is the third and fourth-year students at the Middle East Technical University (METU) Department of Industrial Design. Non-probability purposive sampling was used (Kumar, 2011). The first criterion was to include participants with design knowledge at a basic level. The second criterion required participants to have no history of neurological diseases. The study initially aimed to recruit 20 participants. However, the final sample size was 18. This was primarily due to the difficulty in meeting the sampling criteria, particularly the requirement that participants not be using any psychological or cognition-related medications. Another reason was the timeline of the experiments, which extended beyond the end of the academic semester due to technical complications encountered during the process. Moreover, one of the participants was eliminated from the experiment because the impedance level could not be lowered. In the end, the 17 participants were able to complete the experiment.

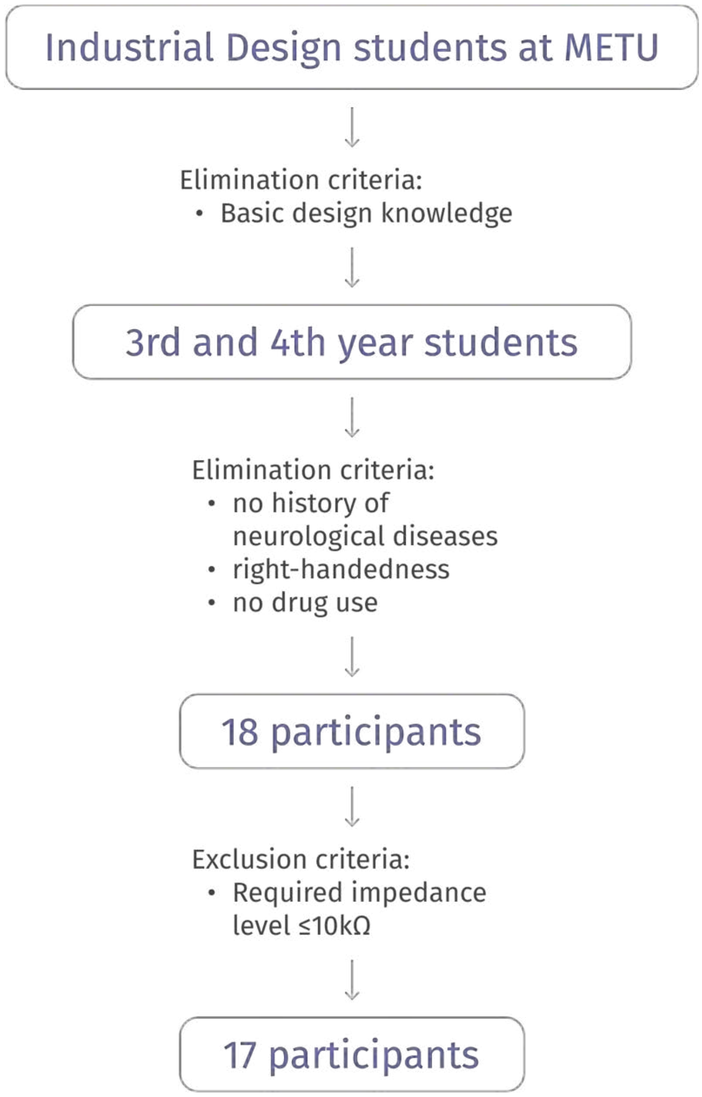

Figure 3.2 Sampling strategy

The following table shows the participants' information for the pilot and actual studies. The first three participants participated in the pilot studies. The number of participants for actual studies is 17. While 9 of them were women, 8 of them were men. Besides, six of the participants were 3rd-year students, and 11 of them were 4th-year students.

Table 3.1 Sampling of the study

	Participants	Grade	Sex
Pilot studies	**P1**	Ph.D.	Man
	P2	Ph.D.	Woman
	P3	Recent graduate	Man
Actual studies	**P4**	4th year	Woman
	P5	4th year	Woman
	P6	4th year	Man
	P7	4th year	Woman
	P8	3rd year	Man
	P9	4th year	Woman
	P10	4th year	Woman
	P11	4th year	Woman
	P12	4th year	Man
	P13	3rd year	Woman
	P14	4th year	Man
	P15	3rd year	Woman
	P16	4th year	Woman
	P17	3rd year	Man
	P18	4th year	Man
	P19	4th year	Man
	P20	3rd year	Woman
	P21	3rd year	Woman

3.3 Research Design

This section provides a detailed explanation of the data collection procedure, the instruments utilized for data collection, and the experimental setup.

3.3.1 Research Framework

As this research aims to understand the role of incubation in design creativity by combining neuroscience and design research, the research framework is created with the consideration of collecting saturated enough qualitative data before and after the experiment phase. Additionally, within the experiment phase, the aim was to decrease the ecological validity and task durations while increasing the interaction for response kinds to meet the requirements of a lab experiment.

The research framework of the study is presented in Figure 3.3. It can be seen from the figure that the research framework consists of three phases, which are pre-experiment self-reports, the experiment containing several phases, and post-experiment product assessment. The phases are designed to be complementary. While the self-reports aim to gain insight into individual creativity, the experiment focuses on the creative process and cognitive mechanisms underlying an incubation period, and the product assessment evaluates the ideas of the participants generated during the experiment session. The approach to each measure's score method and outcome variables are shown in Table 3.2 based on Creswell and Creswell's (2018) introduction of quantitative research methods.

As can be seen from Table 3.2, each research question requires addressing variables in different manners. While answering research question 1.1 (RQ1.1), the sketches of participants, which are derived from experimental conditions (existence or non-existence of incubation period), are approached as the dependent variable, and the creative potential of a participant is taken as a confounding variable. Regarding RQ2.1, the difference between neural activity in the relative difference between the incubation period and resting period is addressed as the independent variable. In this procedure, similar to RQ1.1, creative potential is the confounding variable, and idea sketches are the dependent variable. Concerning RQ2.2, creative potential is approached as an independent variable, and the analysis looks at its effects on cognitive mechanisms.

Table 3.2 Relationship between research questions and variables

Main Research Questions	**RQ1: How does an incubation process affect the creative performance?**	**RQ2: How is brain oscillatory activity modulated during the incubation period?**	
Sub-research Questions	RQ1.1: Which metrics differ at the end products between incubation and non-incubation conditions?	RQ2.1: How do differences between the resting state and incubation state affect the end products?	RQ2.2: How is an incubation period affected by creative potential?
Independent Variable	Incubation condition and control condition	Relative difference between incubation state and control state $(X_1 - X_2 / X_2)$	Creative potential (Y)
Confounding Variable	Creative potential (Y)	Creative potential (Y)	
Dependent Variable	Creative performance (Z)	Creative performance (Z)	Relative difference between incubation state and control state $(X_1 - X_2 / X_2)$
	Incubation vs. non-incubation condition (within-subject)		*Incubation condition (between-subject)*

Data drived from...

Self-reports *Experiment* *Idea sketches*

Variables

X_1: Neural activation during incubation state

X_2: Neural activation during resting state

Y: Creative potential

Z: Creative performance

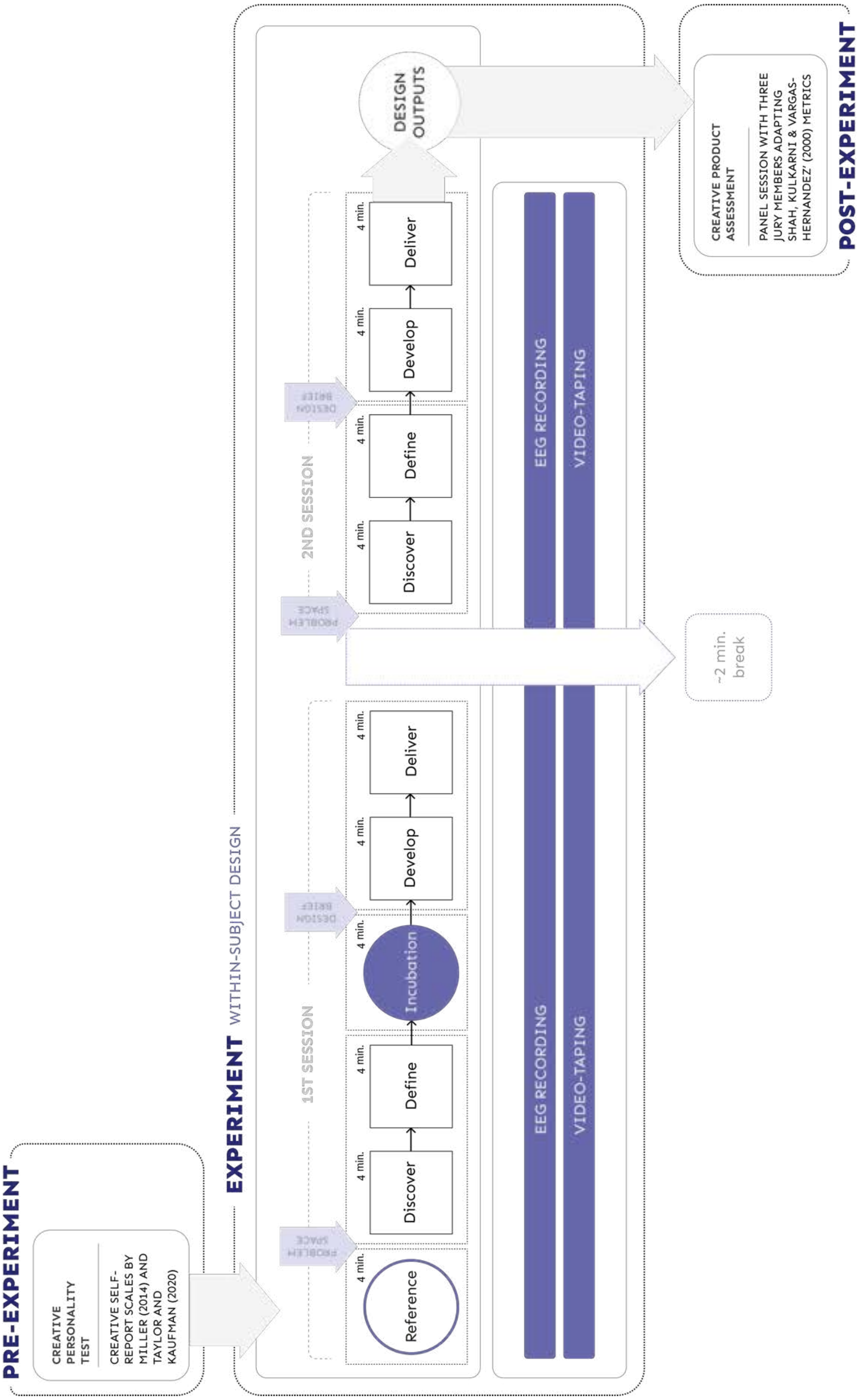

Figure 3.3 Research framework

The following table shows the relationship between what is measured during data collection, how these measures are scored, and what variables they become.

Table 3.3 Measures, score methods, and outcome variables employed in the study

Measure	Score method	Outcome Variable
Self-report (Taylor and Kaufman, 2020)	Guideline-based scoring for creative motivation	Creative potential (Y)
Self-report (Miller, 2014)	Guideline-based scoring for creative cognitive processes associated with creativity	Creative potential (Y)
Oscillatory data collected during the resting state	Spectral analysis	Neural activation during RS (X_2)
Oscillatory data collected during the incubation state	Spectral analysis	Neural activation during IP (X_1)
Idea sketches	FBS ontology, Genealogy tree, Novelty, Variety, Quantity metrics	Creative performance (Z)

As the table provides an overview of data handling, the approach to score methods and outcome variables will be further explained in the following sections.

3.3.2 Preparation for Research

The design of this research required me to undertake a variety of tasks across different domains. One key area focused on the experimental phase, where I worked on setting up the lab, repairing broken hardware, and updating the necessary software. In the process, I developed technical knowledge and improved my hands-on skills. I also learned how to use specific software for presenting the experiment, recording brain signals, and synchronizing the workflow.

To streamline the study, I digitized the experiment flow and created visual materials, including the visuals used in the presentation. we also developed the design tasks to be presented to participants during the experiment. To support the design process, I created a Miro board to be used across its three phases. Additionally, I designed invitation visuals and prepared texts for invitations, posters, and social media posts.

Furthermore, I transferred the creativity self-reports into Google Forms and prepared detailed information sheets to inform participants about the procedure. These tasks ensured that the experimental setup and participant experience were well-structured and seamless. To provide guidance for researchers who want to combine neuroscience aspects with design studies, I present my timetable in Figure 3.4.

As can be seen from Figure 3.4, doctoral qualification exams took place in May 2021, in which I provided an intense report on the literature and proposed five research routes, and I found to be qualified for conducting this study. With the help of the jury members' feedback, I narrowed down the research scope and decided on the research questions. Then, I submitted the thesis proposal, which was approved in November 2021. The meeting with the thesis monitoring committee, then, repeated every six months until I participated in an Erasmus traineeship in the fall and spring semesters of the 2023-2024 academic year. Shortly after the thesis proposal was approved, I prepared my research design and applied to the METU Human Research Ethics Committee in November 2021 with all details regarding the process. The study took the approval of the committee in January 2022.

Figure 3.4 Calendar showing thesis timeline

Once the approval arrived, I started to work on the research design, coding, preparation of materials, and lab environment. These steps are discussed in detail in the following sections. Along with preparations, almost two semesters were spent on technical problems I encountered at the lab. Once the problems were partially solved and partially scoped in a different way, on the 27th of January 2023, the first pilot study was conducted. In February 2023, the experiment phase was granted by

TUBITAK (Scientific and Technological Research Council of Türkiye). Following three pilot studies, on March 24, I was finally able to conduct the first experiment. The experiment phase took between March to September. Although the schedule of the experiments varies, I either conducted one or two experiments per week, apart from holidays and personal engagements.

3.3.2.1 Coding

To avoid influencing participants' psychological states and brain signals with the experimenter's voice, all processes were digitalized using Psychtoolbox (PTB), an open-source toolbox widely utilized by neuroscientists for designing experiments with precise synchronization. I familiarized myself with the function structure of PTB and programmed the entire experiment phase. Since PTB operates within MATLAB, I used the MATLAB programming language to visualize the experiment. The coding and programming phase required approximately six months to complete.

Following the coding phase, it was necessary to integrate the code I developed with the operating systems used in the lab, establish connections between devices, and configure the system settings. At this stage, Igor Mapelli, a computer scientist and former researcher at the lab, played an active role in the maintenance and integration process. Igor had previously collaborated with my co-supervisor, Assoc. Prof. Tolga Esat, during his doctoral studies.

The integration process, which was anticipated to take less time, was extended over six months due to unexpected issues. The primary challenge arose from compatibility problems between operating systems and devices, likely caused by updates to the lab computers. Despite these efforts, the intended outcome—to fully automate the marking of the beginnings and endings of the resting and incubation periods—could not be achieved. Due to persistent technical difficulties with the computers and operating systems, we ultimately decided to proceed with manual marking after approximately six months of troubleshooting and adjustments.

In addition to coding in MATLAB, I designed the visuals for the interface to be presented to participants during the experiment. This process, which took approximately one month, was completed using Adobe Illustrator. The visuals displayed on the computer interface during the experiment are included in Appendix B for reference.

3.3.2.2 Forms

Several forms were prepared for the study to ensure ethical compliance and maintain the integrity of the experimental process. A participant consent form (Appendix C) and a confidentiality agreement (Appendix D) were created to ensure that all participants understood their rights and the confidential nature of the study, as the same tasks were used across all experiments and it was important to prevent participants from sharing information with each other. Additionally, a post-participation information form (Appendix E) was prepared to be distributed after the experiment. This form clarified the true aim of the study, which was to investigate the incubation effect. Participants were initially informed that the experiment focused on design cognition to avoid biasing their behavior during the experiment.

3.3.3 Environmental Setup and Instruments

In this study, two instruments are employed in data collection: self-reports used before the experiments and electroencephalography (EEG) used during the experiments. The rationale for employing them is addressed in this section.

The self-reports aim to investigate one's creative potential to further examine its effect on creative performance and the relationship between neural mechanisms.

They were conducted at the lab via Google Sheets before the experiments started. The self-reports used in this study are Miller's self-report measure of Cognitive Processes Associated with Creativity (CPAC) and Taylor and Kaufman's Creative Trait Motivation scale (CTMS). While CPAC measures thinking skills in relation to creativity, the CTMS measures one's intrinsic, extrinsic, and amotivation traits.

CPAC assesses the usage of and beliefs regarding the value of the creative, cognitive processes in problem-solving (Rogaten and Moneta, 2015). The seven creative subprocesses are evaluated to interpret one's preferences at different stages in creative problem-solving. The assessment of cognitive strategies adopted by the person via this self-report is seen as a reliable method to interpret one's underlying cognitive mechanisms in the creative process and understand the differences between persons.

CTMS takes a basis on Amabile's Componential Theory of Creativity, developed in 1983, suggesting that one's creative performance is associated with domain-relevant skills, creativity-relevant skills, and task motivation. While domain-relevant skills are the technical know-how and expertise needed to make a contribution to a specific domain, creativity-relevant skills are individual variances in cognitive processes, such as flexible thinking ability that advantages creative performance, and heuristics (Taylor and Kaufman, 2021). Task motivation encompasses two concepts: trait motivation, which is an individual's overall attitude toward a task and how well it aligns with their interests, and state motivation, which is their belief about why they should do the work at hand. The scale is developed to fill the gap for assessing trait motivation and can be adapted in domain-specific studies.

The approach in this study advocates that creativity is a multidimensional phenomenon and one's creative potential should be considered when creative performance is investigated. Therefore, in this study, while domain-relevant skills are aimed to be controlled with the sampling selection, creativity-relevant skills are evaluated with, CPAC, and creative motivation is assessed with CTMS.

EEG is employed to investigate the cognitive mechanisms underlying an incubation in a creative process. Various neuroimaging tools use different mechanisms to track brain activity and have different positive and negative aspects according to the research aim and protocol. Some tools gather information by recording the brain's electrical activity, known as electrophysiological methods, such as electroencephalography (EEG) and the magnetic field of electrical activity, i.e., magnetoencephalography (MEG). There are functional imaging methods, a.k.a. hemodynamic methods, that gather information by tracking physiological changes in the blood flow, such as functional magnetic imaging resonance (fMRI) and functional near-infrared spectroscopy (fNIRS) (Ward, 2015). Electroencephalography is defined as the method of using electrodes mounted to the scalp to capture electrical activity patterns in the brain as lines on paper (Sobel and Li, 2013). The non-invasiveness of this technique, along with the high temporal resolution it provides, are seen as major advantages. However, it has lower spatial resolution, and it is highly sensitive to noise (Sobel and Li, 2013). Also, although the studies' aims differ significantly, a solid basis for integrating EEG research into design research is provided in the literature by its long tradition (Seitamaa-Hakkarainen et al., 2014).

Since EEG is highly sensitive to electrical currents, including interference from electrical devices and power lines, an ideal setup requires a Faraday cage, a room with walls lined with conducting material, to minimize external electrical noise and ensure accurate recordings.

The experiments were conducted at the Neurosignal Laboratory located in the Graduate School of Informatics at METU (Figure 3.5). The EEG experiment was held in the Faraday cage at this laboratory (Figure 3.6).

Figure 3.5 Inside the laboratory: The desktop on the left side is used for data recording, the second one is used for presentation, and the desktop on the right side is used for data analysis.

Figure 3.6 Left: The look from the outside of the Faraday cage. Right: The look from the inside of the Faraday cage.

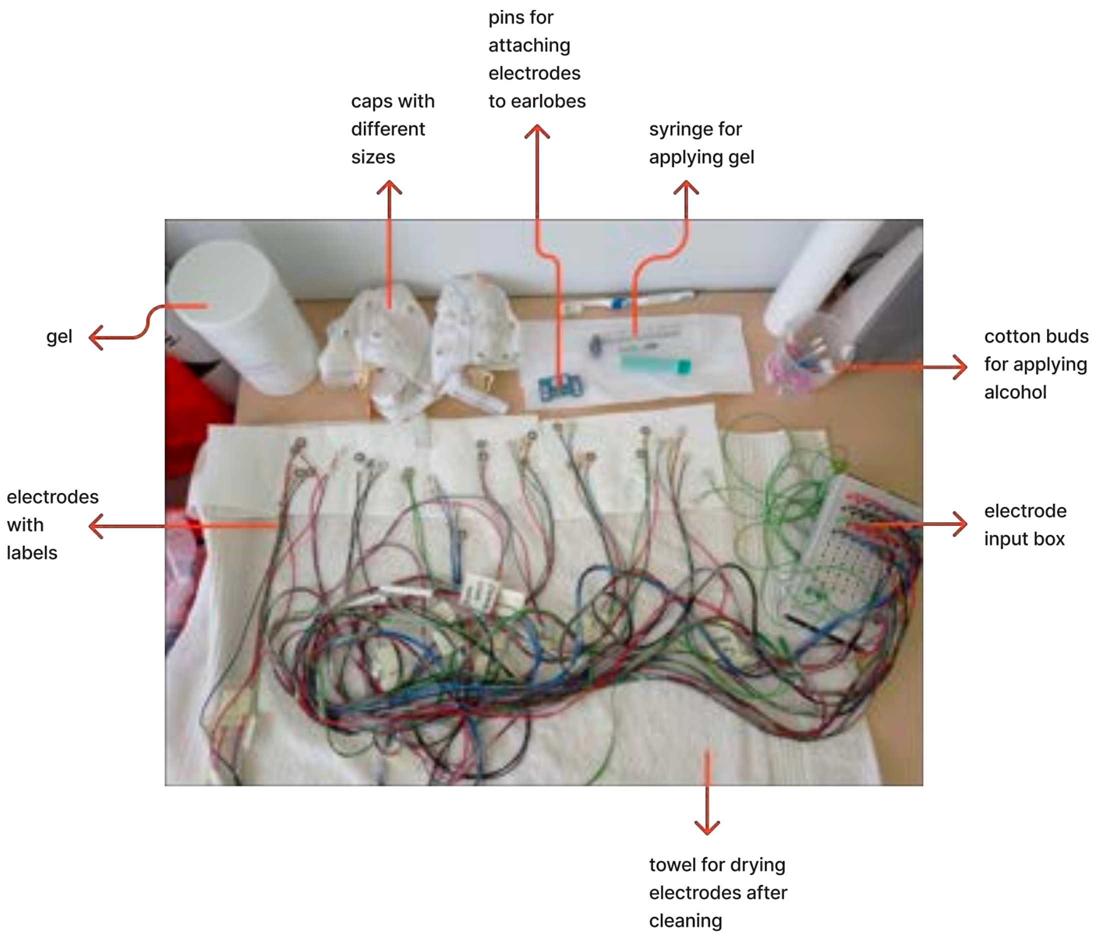

Figure 3.7 Materials used during the experiment

We did two trials on different days with two volunteers to test the EEG device and software. The photos show the participants' preparation phase. The aim was to try the device, learn and experience the steps, and record eye-open and eye-closed data. The first trial, on the 23rd of February, 2022, was unsuccessful because of the technical mistake we made, but the second trial, on the 18th of March, 2022, was successful, and we collected eyes-open and eyes-closed data.

Looking at Figure 3.8, the photo on the left was taken during the very first trial of the EEG device. It represents the phase in which the cap was worn, the scalp was cleaned by using cotton buds for each hole, and each electrode (32 electrodes in total) was placed according to its position. The photo on the right was taken during another session, and it shows the following phase in which the participant was positioned in front of a computer in the Faraday cage.

Figure 3.8. Left: The first trial during the preparation. The cap is worn, and each electrode is attached to its place. Right: In the Faraday cage while the gel is applied to the electrodes.

During this phase, whereas one researcher was applying the gel and trying to lower impedance levels for each electrode, one researcher followed the impedance levels on the computer screen and guided the former. It is needed to lower the impedance level below 10 kΩ (kiloohm) (Górecka and Makiewicz, 2019). For each participant, the length of the process might differ due to the skin properties. Brainvision Recorder[1] software is used after participant is positioned in the Faraday cage to check impedance levels, record, and export EEG data.

[1] https://brainvision.com/products/recorder/

3.3.3.1 Materials for Pre-experiment Procedure

The experiments were conducted with an assistant. Each participant signed the following documents before the experiment began: (1) Confidentiality agreement (Appendix D) and (2) Consent form (Appendix C).

Before preparing the participants for the EEG experiment, the steps below were followed:

1. An information sheet about the design process was given to each participant (Appendix F).
2. Creativity self-reports were answered in Google Forms using the researcher's computer at the lab. The original documents are in Appendix G.
3. A mini-tutorial on graphic tablet use and what participants would face during the experiment was given.

3.3.3.2 Materials for the Intra-experiment Procedure

After the pre-experiment surveys were conducted and participants were prepared for the experiment, the process continued with the experiment phase, which was conducted in a controlled lab environment. It should be noted that the participants were not informed beforehand that they would undergo an incubation period during the design process and the experiments were conducted to understand the incubation effect.

The experiment consists of two conditions, one of which includes a design process with an incubation period given in the middle, and the other is a continuous design process. They are called incubation condition (experiment condition) and control condition, respectively. They follow the steps of the Double Diamond design model: discover, define, develop, and deliver. The model's theoretical aspect is addressed in the literature review section (2.2).

Each step was set to a duration of 4 minutes, totaling 20 minutes for the incubation condition and 16 minutes for the control condition. The primary rationale for maintaining a 4-minute step length was to minimize movement-related artifacts and reduce fatigue caused by environmental conditions and the requirement to remain still. Additionally, previous studies highlight the effectiveness of rapid idea generation techniques, such as 6-3-5 (Wright, 1998), in fostering creativity. Research suggests that idea generation productivity declines after the first few minutes, with a rapid initial burst followed by a steady decrease (Liikkanen et al., 2009). Studies also indicate that decomposing tasks into smaller time segments can help maintain productivity while balancing creativity (Dennis et al., 1996; Karau & Kelly, 1992). Therefore, this interval was deemed appropriate for studying design cognition within a controlled laboratory setting.

The decision to use the Double Diamond design model as the core structure of the experiments was based on several factors. First, since the participants were design students from the METU Department of Industrial Design, it was essential to follow a process they were already familiar with. The Double Diamond design model is taught in one of the mandatory courses in the department, ensuring its relevance and accessibility to the participants. Second, the model's widespread recognition in design theory and practice makes it an appropriate choice for this study, as it bridges theoretical concepts with practical applications. This alignment supports the exploration of incubation's impact on design practice within the research framework. Lastly, the model's structured process allows the researcher to segment the design process into phases of equal length, facilitating comparisons with the creative process phases examined in this study.

Each step of the experiment lasts 4 minutes. The experimental sessions always begin with the incubation condition to minimize the effect of anticipation during the break. Additionally, since the duration of the experimental sessions is significantly longer than those typically applied in neuroimaging studies, the incubation condition is placed at the start. This arrangement helps mitigate the risk of losing electrode connectivity over time, which can occur due to participants' body movements during the session.

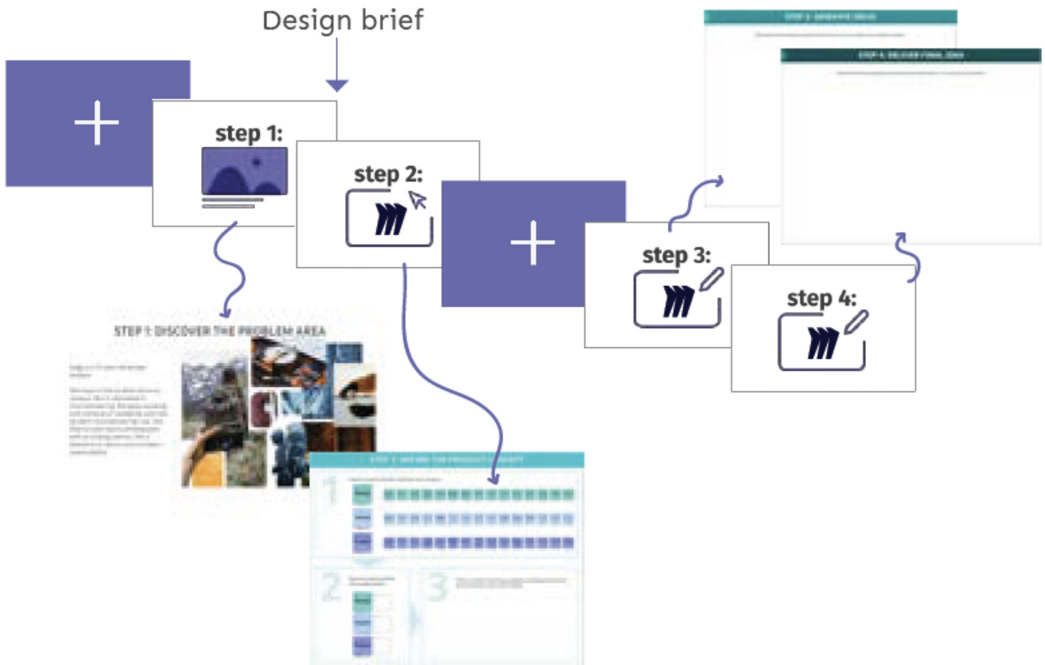

Figure 3.9 The flow of the EEG experiment

The figure represents the steps of the incubation condition: It starts with recording resting-state data for 4 minutes, in which participants are instructed to stay stable and close their eyes. In case of opening their eyes, they are expected to fixate their vision at the cross mark at the center of the screen (Figure 3.10)

Figure 3.10 Screen with a fixation cross

Participants hear a recorded voice saying, "You can now open your eyes." Following this, the discovery phase begins, during which all information related to the problem, including the persona and mood board, and benchmarking, is presented. Benchmarking aims to compare a particular product or process with other successful products or processes, to evaluate any shortcomings and develop strategies to improve it (Erlhoff and Marshall, 2008). Providing benchmarking to participants allows them to define user needs better and address gaps. A persona is a fictional representation of a target user, created to embody their needs, behaviors, and goals (Erlhoff and Marshall, 2008). While personas help participants to empathize with users, it is supported with a mood board designed to convey a specific mood with an image collage aiming to help participants align their mindsets.

This is followed by the problem definition phase, in which participants choose keywords for the product context and make a problem statement. The purpose of guiding participants to make a statement before transitioning to the idea generation phase is to help them construct a schema that systematically connects person, product, and interaction.

Then, an incubation period of 4 minutes takes place. Following this, participants proceed to the idea generation phase and then deliver their final idea. For the last two steps, participants used a graphic tablet for carrying out idea generation.

The design tasks used in the experiment are designed to build on the knowledge provided in the literature review (section 2.2.1) on the nature of design problems. The red triangle in Figure 3.11 shows how the problem type is positioned in this study. The tasks are ill-structured to represent design problems but familiar or knowledge-lean to enable participants to produce solutions without the need for new information.

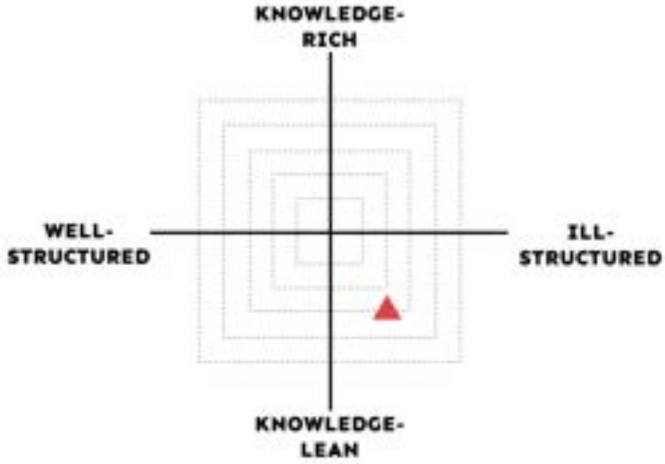

Figure 3.11 Classification of problems

Discussing those contributors within this study, the two problems that are given as tasks during the experiments are formed with the consideration of (1) the nature of design problems, (2) participants' familiarity with the problem area, and (3) participants' knowledge and expertise.

One of the problems is a water bottle, and the other is a portable Bluetooth speaker. The study of Laxman (2013), in which he conducts a set of case studies with design students to understand the effect of the structuredness of the problem on the problem-solving process and outcomes, highlights the need to provide a space for students to understand the nature of the given problem and then develop a strategy for solving that. In line with that view and taking the time limitation of the experiments in this study into account, the experiment content and flow are constructed to provide students a medium in which they can make a clear definition of the problem in advance of idea generation. The persona and benchmarking, therefore, are provided to participants to scope the problem and allow them to come up with solutions within a limited time. It is expected for participants to design within the scope of defined personas and with consideration of benchmarking. The mood boards and benchmarking were generated in Figma[2] to display during the experiment via PTB presentation. It should be noted that the screen designs changed slightly after the pilot studies, which is explained in Section 3.4.1. The screens presented here are the final versions.

Figure 3.12 shows the screens for problem one. During the discovery phase for this design problem, a mood board along with short information about the persona, Doğa, is given. On the second page, while the text-based information continues, now a benchmarking on the water bottles is shown to the participant. Both of these pages stay present for 2 minutes on the screen. Participants cannot go back or forward. This limitation is set to achieve the same conditions in all participants. On the third page, the design brief is given with just a single sentence. For this problem, the brief is *to generate ideas for a water bottle suitable for Doğa.* Together, these three screens form the 'Discovery' phase of the design process and take 4 minutes in total. On the design brief page, there is no countdown, instead, the participant presses the space key to continue.

The second design problem used in the experiment can be seen in Figure 3.13. Likewise, a mood board along with short information about the persona, Ekin, and a benchmarking on portable Bluetooth speakers are shown to the participant. For this problem, the design brief is *to generate ideas for a portable Bluetooth speaker suitable for Ekin.*

Participants' feedback was used instead of a countdown timer to ensure that each participant consciously read the sentence and pressed the button to proceed to the third page. Additionally, the order of the design tasks was counterbalanced throughout the experiment flow to prevent order effects.

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[2] An internet-based design tool, www.figma.com

Figure 3.12 Three screens showing the pipeline: Persona, benchmarking, and design brief

The discovery phase ends when participants press space to continue. At that moment, the PTB presentation shrinks to the top of the screen and turns into a countdown timer, and the code triggers a Chrome page with the Miro workspace open. The screen is seen in Figure 3.14.

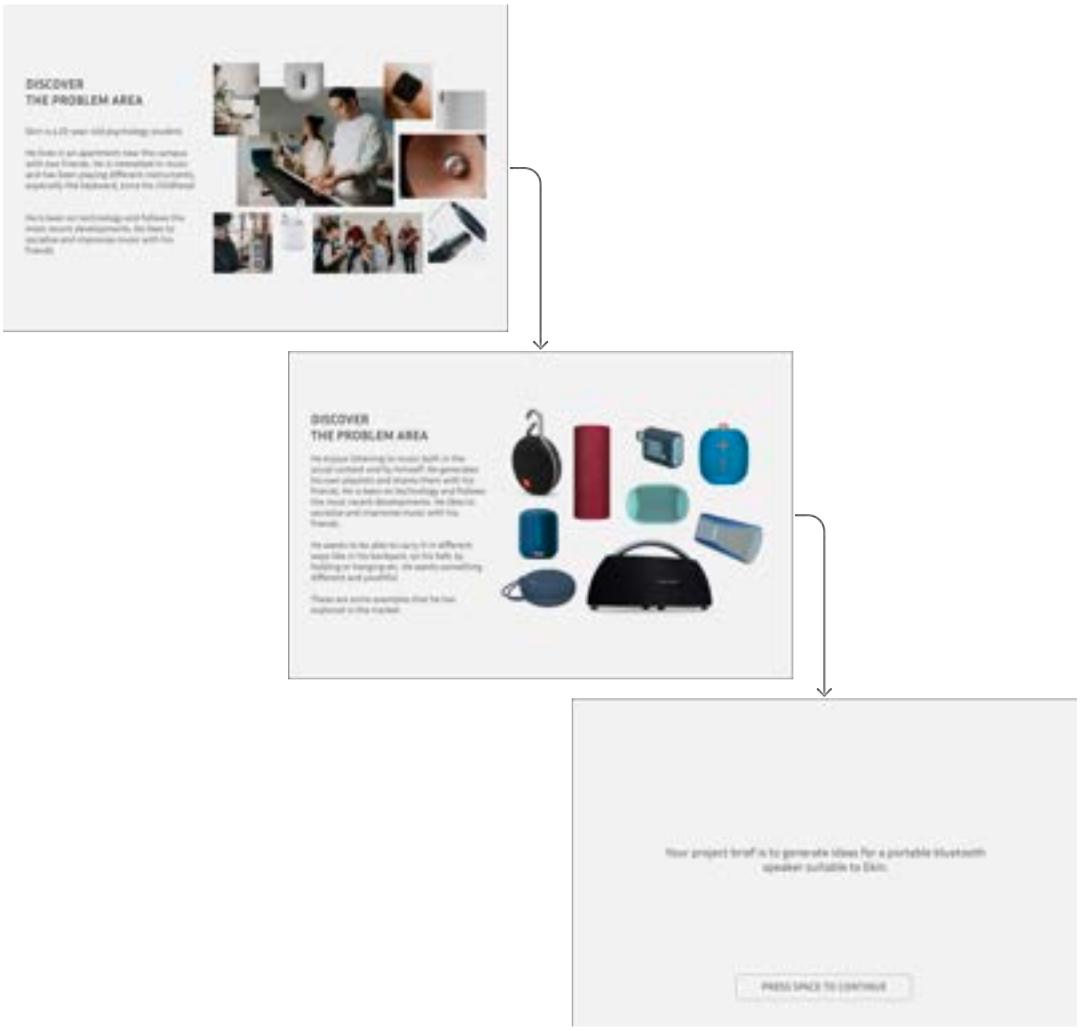

Figure 3.13 Three screens showing the pipeline: Persona, benchmarking, and design brief

Figure 3.14 Miro workspace and countdown timer

I created the Miro workspace that participants used in Step 2 (Definition phase), Step 3 (Discovery phase), and Step 4 (Delivery phase). During Step 2, which corresponds to the problem definition phase, an artboard containing three steps is designed. The first step contains three categories (person, product, context) with 15 properties sorted for each one. The participants are expected to choose one word per category and place the keyword chosen in the area marked with the number 2. The categories and the adjectives are formed to comply with the framework of human-product interaction. It was also considered to provide different keywords for each category to prevent confusion.

The following model developed by Hekkert and Schifferstein (2008) to address product experience provides a basis for this categorization. The model addresses the attributes of humans, products, and how they interact with each other.

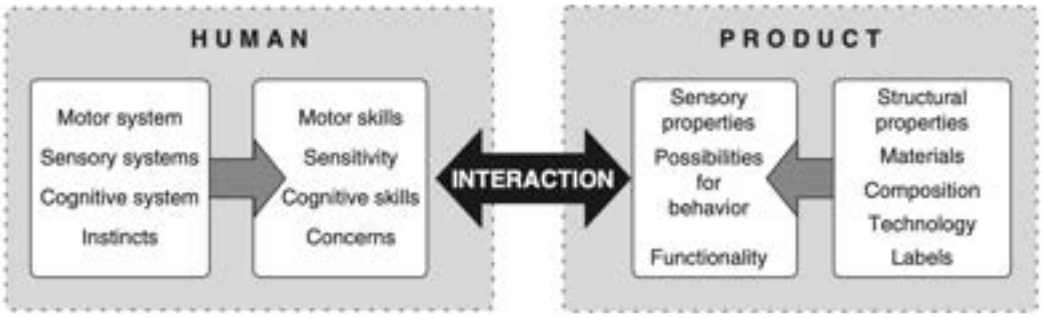

Figure 3.15 Model of human-product interaction by Hekkert and Schifferstein (2008, p. 3)

In their essay on understanding interaction, Hekkert and Dijk (2011) mention that they approach product properties in a similar way to human properties. These human attributes can be defined by physical properties and sensory and motor systems. However, when humans and products interact with each other in a particular environment, things start to shape and be shaped. They continue as follows:

> "Our capacities become skills, expertise, taste, and sensitivity, our basic concerns turn into goals, motives, needs, and intentions, and our behavior reflects a certain personality or temperament. These human aspects can only be defined in relation

> to an external world. […] These human attributes only have value in relation to the external world (Hekkert and Dijk, 2011, p.240)."

A similar definition is made for product properties, too. The key that they mention here is that there are some attributes and properties belonging to a person or product that can only be described relative to each other. The person operates on the environment via motor skills, then perceives the product via the sensory system, and the cognitive system makes sense of it (Schifferstein and Hekkert, 2008). Hence, the product takes meaning, beyond its material properties.

The keywords for each category can be seen in the following table:

Table 3.4 Keywords indicating different properties used in the experiment for three categories: person, product, and context

Person	**Product**	**Context**
Curious	Minimal	Noisy
Relaxed	Portable/ Mobile	Crowded
Busy	Modular	Natural
Fun	Long-lasting	Scattered
Outgoing	Affordable	Wild
Idealistic	Recycable/ Renewable	Collaborative
Detail-oriented	Simplistic	Domestic
Lazy	Textured	Dynamic
Analytical	Vintage	Comfortable
Organized	Flexible	Boring
Motivated	Transparent	Calm
Responsible	Honest	Stimulating
Friendly	Emotional	Motivating
Ethical	Natural	Impressive
Serious	Hi-tech	Active

The person keywords are diverse attributes corresponding to different cognitive (ethical, analytical,…), motor (relaxed, serious,…), and sensory skills (detail-oriented). These characteristics imply the product experience. Clarkson (2008, p. 168) gives an example of opening a juice box by indicating how these three capabilities take role in product experience: "Perceiving: Sensing where the opening is. Thinking: Determining how to open it. Acting: Carrying out the movements required to actually open the carton." Each of them corresponds to sensory, cognitive, and motor capabilities respectively.

Although cues for product qualities are provided through benchmarking and the persona, participants are expected to assign one of the sensory attributes from the given list to the product. This step ensures that their concrete definition or statement establishes a clear path toward a solution considering the time limitation.

The context keywords point out the context of use slightly more than the interaction itself. Because, this analysis of it will enable participants to construct a context in which the product will be used to define the requirements of users and products (Maguire, 2001).

Following the keywords, participants are expected to write a sentence indicating their problem formulation around the keywords they have chosen (Figure 3.16).

During Steps 3 and 4, participants are directed to Miro after being given information about each step. During step 3, they are expected to generate ideas through sketches, and during the last step, they are expected to choose one of the ideas they had generated during the previous step and finalize it to deliver. The whole artboard is presented in Figure 3.17.

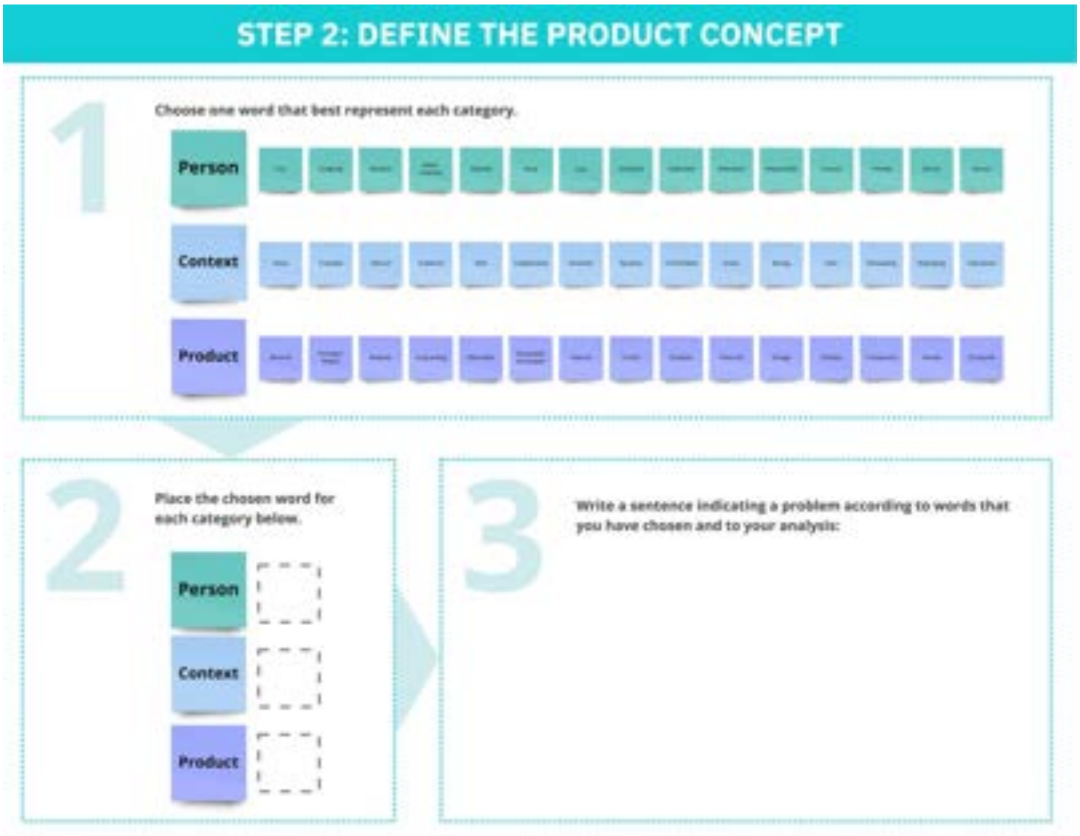

Figure 3.16 Artboard created in Miro workspace for Step 2

Figure 3.17 Miro artboard consisting of Steps 2, 3 and 4

3.3.3.3 Materials for the Post-experiment Procedure

After the EEG experiment, a short online questionnaire was conducted in order to understand their experiences during the experiment. A post-participation information form explaining the study's aim was also given (Appendix E). After this questionnaire, participants had a chance to wash their hair in the bath located in the same building.

3.4 Data Collection

Although the data collection procedure took place at the lab, a day before the experiment, I got in touch with each participant in order to give them more detailed information about the procedure and remind them of the meeting and requirements related to alcohol/substance intake.

On the experiment day, when a participant arrived at the lab, the first thing we did was to obtain their consent and agreement on confidentiality. These materials were explained in more detail in Section 3.3.2.3.

It was necessary to conduct ancillary investigations related to the EEG experiment to know whether there were any external factors affecting the nervous system of a participant, such as the amount of sleep, caffeine or substance intake, and medications (Pernet et al., 2018). Therefore, just before the data collection process began, a short questionnaire was conducted.

After this, the data collection process started with the creative personality tests. Participants answered two self-report questionnaires via Google Forms. This process took approximately 10 minutes on average.

Then, the preparation process started, the duration of which varied from 30 minutes to 90 minutes, depending on the participant. The exact times were documented in an Excel sheet. The preparation process was completed when the impedance levels were lowered under 10 kΩ.

Then, EEG recordings, video-taping, and non-participatory observations took place during the experimental sessions. The order of the sessions was counterbalanced to randomize the order of tasks to limit the learning effects (Rubin and Chisnell, 2008). After each session, a short questionnaire via Google Forms took place to gain insight into participants' approach to their performance and whether they thought consciously about the problem during the incubation period. After the experiments were completed, the idea sketches were organized for the assessment with two coders.

Figure 3.18 presents the photographs that were taken during different phases of these sessions. The first photo shows the EEG mounting phase that was held at the lab. The second photo shows the gel application after mounting the electrodes in their places according to guidelines. The third photo shows the process of lowering impedance levels within the Faraday cage, and the following one demonstrates when the participant gets familiar with the Miro artboards and drawing tablet. The last one is taken while the experiment is running. The researcher monitors the signal recording (the monitor on the left), controls the experiment flow (the PC at the center), and observes the participant via video recording (the monitor on the right.)

In respect of experimental sessions, each participant participated in two sessions on the same day. Also, although the EEG setup stayed mounted throughout the experiments, the data collected only during the resting period and incubation period were analyzed.

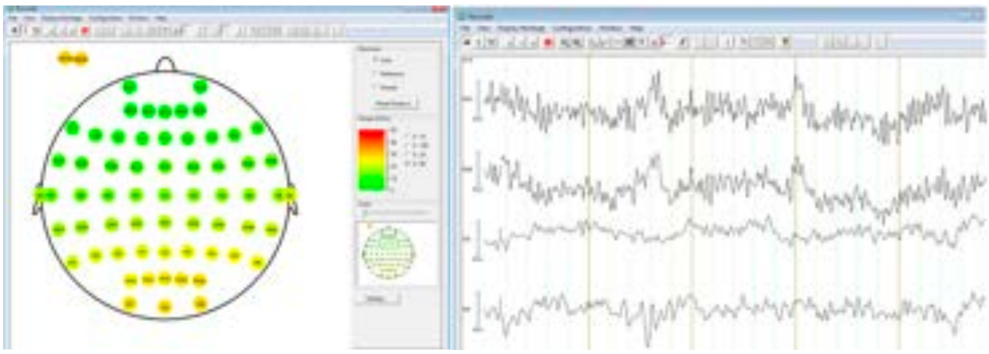

Figure 3.18 Left: The interface of the schema used for impedance level check. Right: the EEG data recording (Images are taken from BrainVision Recorder User Manual, 2016).

Figure 3.19 The steps of preparation at the lab

After lowering impedance levels, the participant was left in the Faraday cage, and the door of the cage was closed. The EEG recording was started first, and the video recording and the presentation were started after. There was a camera in the cage in case of an unexpected issue. Figure 3.19 shows the interface of the Brainvision Recorder software that is used to check impedance levels.

Overall, the first phase, the creativity self-reports, took up to ten minutes; the participants’ preparation for the EEG experiment, which is different from person to person, took approximately 45 minutes on average, and the experiment lasted for another 50 minutes, consisting of two conditions with a couple of minutes of break in between. The whole process lasted about 2 to 2,5 hours.

3.4.1 Pilot Studies

On 27.01.2023, the first pilot study was conducted with a Ph.D. student in the METU Department of Industrial Design. During the experiment, a timer error related to the code caused shorter design phases to be allowed for the participant. The preparation period took longer than expected (approximately two hours), this was because it took some time to lower the impedance level and probably due to the limited experience of the researcher. The experiment took approximately 40 minutes to complete.

After this study, the verbal and visual information provided to the participants via presentation were combined, and the number of images/steps to be followed for the design task was reduced (Figure 3.20). Also, the countdown timer’s code was refactored.

Figure 3.20 Left: The previous version. Right: The revised version.

On 16.02.2023, the second pilot study was conducted in a silent environment without using EEG with another Ph.D. student in the same department. The aim of this pilot study was to prove that the decisions about the experiment design were correctly taken. During this experiment, it was observed that the duration for the discovery phases was long. It was also seen that there is a need to remind participants to change the screen by pressing the space at each screen. Besides, it was realized that a major change was needed for the ordering strategy. When the incubation period was given during the second design process, the participant became aware of the phases because she learned them during the first design process. This caused her to think consciously about the problem and try to find a solution during the incubation period, which was an undesirable situation. Therefore, after this pilot study, the incubation period was fixed to be given during the first design process, but the design tasks' order would be counterbalanced. Also, a short expression was added at each visual, instructing the participant to press space in order to change the screen (Figure 3.21).

On 18.03.2023, the third and final pilot study was conducted in the lab by using a different EEG system. This experiment aimed to confirm the changes in the experimental design and to test the Muse headband[3] to see the quality of data to use

[3] Muse headband is a mobile EEG system with 4 electrodes, originally launced for meditation and personal use. https://choosemuse.com/

this tool in case of need. During this experiment, it was seen that there was an additional need to introduce the Miro workspace; even though the majority of the students had used it before, the artboard usage seemed different to them. Therefore, a simplified image of artboards to navigate them was added to this introduction page (Figure 3.22).

Figure 3.21 ‘Press space to continue’ was added to the images without countdown timers.

Figure 3.22. The introduction image used in the experiment to introduce Miro workspace

With those changes, the experimental design took its final version and I started to make the call for participants to take part in the actual experiments.

3.4.2 Actual Studies

I applied to the TUBİTAK 1002-B project to have an assistant in the lab in February 2023. This TUBİTAK project specialized for studies that were already started but lacked equipment or needed a scholar. Also, the project evaluation takes approximately ten days, shorter than other TUBİTAK projects. Along with requesting a scholarship for a student assistant, I requested equipment and consumable materials for lab use. After the project was accepted, I prepared a call for a scholar who was studying for their master's or doctorate degree within the Informatics Institute. The call was announced with e-mails and posters that I put up in the institute. Four people applied to it. My co-advisor and I scheduled interviews with these candidates. We decided to recruit a student from Cognitive Sciences. After my second experiment, we started to conduct experiments with him.

3.4.2.1 Recruitment Process

To recruit participants, we announced the experiment via e-mail, Instagram, and LinkedIn pages of the department, as well as posters and flyers I put on the faculty building (Figure 3.23). These materials were prepared in Turkish and English since the faculty also has foreign students. The first several participants got in touch with the researcher through these announcements. The very first experiment was conducted with one of these students on the 24th of March.

After several experiments were conducted, because less demand started to come in via social media announcements, I visited the fourth-year design studio course to distribute flyers and invite students. I realized that although some of the students were interested in the calls when they encountered the announcements, they hesitated to get in touch for some reasons. So, being in the studio, chatting with them, and answering their questions about the process helped them clarify their hesitations and me to recruit more participants. I prepared an Excel document to save the appointments.

Figure 3.23 Left: The visual designed to call participants via Instagram and LinkedIn. Middle: The poster to hang at the faculty. Right: The leaflets to hand out.

3.4.2.2 Complications Regarding Experiments

There were some complications that differed from participant to participant. For example, during the second experiment, although the participant said that she was familiar with Miro and the drawing tablet, she had problems navigating the page. During the third experiment, we could not lower the impedance level under 13 kΩ. In the same experiment, I forgot a code snippet to uncomment, which prevented this chunk from running, so we had to restart the experiment. When the fifth participant arrived, I realized that he is using his left hand when signing the consent form. Then we realized that he skipped the criteria of being right-handed, and I failed to confirm that criteria before we met in the lab. So we had to cancel it. During the sixth experiment, the keyboard inputs that trigger markers did not work, so I had to write down the timings manually. In the next experiment, the code stopped working during the resting state, and it could not change the screen to start the experiment, so we had to start over. During the next one, the participant did not close their eyes during the resting state and incubation period. In some experiments, the speaker did not work, so participants could not understand that they could open their eyes, which required the researcher to enter the cage and say that they could open their eyes and move forward within the experiment. One morning, when we met with the participant in the lab for the experiment, we realized that Miro was undergoing maintenance and could not be opened, so we had to postpone it. One of the problems that I could not foresee was the prevalence of antidepressant use. Since I did not expect that this was not something I confirmed while scheduling an experiment, or they were not thinking that this was something that they needed to report beforehand. We had to cancel several experiments after we were appointed because of this. Some of the participants canceled the meeting, or we had to reschedule the experiment due to their engagements.

We faced some maintenance problems during the procedure as well. One day in May, when one of the participants came to the lab, the computer that we recorded the EEG data did not turn on. Overcoming this problem took a month with the help of people from the IT department. Another day, there was no water running within the whole building because of the excavation work in front of the faculty. However, we had already planned an experiment, so my assistant helped the participant wash their hair by pouring water, but we also had to clean the electrodes this way.

I visited the design studio course two times during the experiment phase. Also, I asked participants several times to share the experiment call message within their student WhatsApp groups. I kindly asked previous participants to inform their classmates about the experiment and direct them to me.

All of these above-mentioned problems, along with the ongoing personal engagements of mine and my assistant, the experiments took a long time to complete. Also, due to the inflation in Turkey, we raised the participation fee from 150 Turkish liras to 200 after a while. The final experiment was conducted on the 13th of September, and my co-supervisor and I decided to stop the experiments when we reached 17 participants in total.

Figure 3.24 The photo is taken while we clean the electrodes by pouring water

3.4.2.3 Nature of the Collected Data

The nature of the collected data was both quantitative and qualitative. While the self-reports and EEG recordings form the quantitative dataset, sketches, and video recordings form the qualitative dataset. The table (Table 3.5) below shows the nature, amount, and documentation of each data type.

Regarding self-reports, the data was numerical and was prepared for statistical analysis after grouping the questions into categories suggested by the creators of the scales. There were 34 self-reports in total. Apart from this, there were 17 post-experiment self-reports containing free text and numerical data. Since this survey was used to interpret the result of statistical analysis performed with all data, they were not used for separate analysis within itself.

The video recordings are around 935 minutes of visual data. The average duration is 53 minutes -+15 minutes. These recordings were not used for the analysis but for interpreting the unexpected changes in signal data.

Table 3.5 Nature and documentation of collected dataset

	Quality of data	Quantity of data	Documentation
Self-reports	Numeric, text	34 self-reports 17 surveys *(2 self-reports 1 survey)*	Google Forms & Excel sheet *in Google Drive and local*
Video recordings	Visual	935 minutes *(54 minutes +-15 minutes)*	mp4 *Google Drive and local*
EEG data	Numeric, signal	270 minutes *(136 minutes of interested section)*	.eeg, .vhdr, .vmrk files for each participant *Google Drive and local*
Sketches	Visual	102 pages *(6 page for each participant)*	Miro and pdf *Google Drive, Miro and local*

Regarding EEG data, approximately 270 minutes of signal data were recorded in total. Although the recording was made throughout the first session, 137 minutes of data were used in the analysis, corresponding to the resting state period and incubation period.

Regarding sketches, there were two sessions for each participant, hence 34 sessions in total. Each participant's work was formed by 6 pages (3 pages for each session) and 102 pages in total. The first page contains the step in which the participants choose keywords for person, context, and product and write a sentence in order to formulate their problem definitions, which was converted into an Excel document. The second and third pages were printed in preparation for analysis.

I categorized the data in folders for each participant (P1: EEG data, self-report data, sketch data, and video recording, etc.) and in folders for each data type (EEG data of all participants, Sketches from all sessions, etc.) to prepare it for data analysis.

CHAPTER 4

DATA ANALYSIS AND FINDINGS

The data analysis procedure contains several phases, and the assessment of datasets is different (Figure 4.1). While the review of signal data and self-report data started concurrently with the ongoing experiment phase, a pipeline for EEG data analysis and sketch analysis was constructed after the experiment phase was completed. The following figure shows the datasets that were collected and the corresponding method used for the analysis for each of them. This process is followed by a statistical analysis with within-subject and between-subject designs to answer different research questions.

Figure 4.1 Datasets and analysis methods

4.1 Self-reports and Post-experiment Survey

The two self-reports and one post-experiment survey data were documented in Excel sheets separately. The analysis of self-reports followed the guidelines of Taylor and Kaufman (2021) and Miller (2014). They were conducted before the experiment to collect information about participants' creative motivation and cognitive processes associated with the creative process. The data were first visualized to see the distribution of scores among participants and the sub-categories of the self-reports. All 17 participants were included in the analysis. Then, the results of the self-report questionnaires were analyzed further to reveal any potential correlations with other parameters of the study.

The post-experiment surveys were not analyzed using a predefined method; instead, they were used to interpret the signal data. This survey contains the following questions: Did you consciously think about the design problem you were given while your eyes were closed? If yes, can you express the intensity of your conscious reflection on the problem (on a 1-10 Likert scale)? Do you think there was a difference in your performance between the two design processes? If yes, in which one was your performance better? Why?

4.1.1 Self-report on Cognitive Processes Associated with Creativity

One of the self-reports mentioned above is the Cognitive Processes Associated with Creativity (CPAC) (Miller, 2014) test focuses on specific cognitive processes such as flow and idea manipulation, which are associated with creativity. These processes are foundational for creative potential, representing individuals' mental tools and operations to generate novel and appropriate ideas. The CPAC uses a 1-5 Likert scale from never to always. It requires the researcher to categorize questions with different scores available, under idea manipulation (25), imagery/sensory (30), flow (20), metaphorical/analogical thinking (20), idea generation (30), and incubation (15). The scores are determined by gathering the scores given to each question.

We first checked what the mean score each participant achieves and how it differs across participants. Figure 4.2 below shows the mean scores for these sub-categories for each participant.

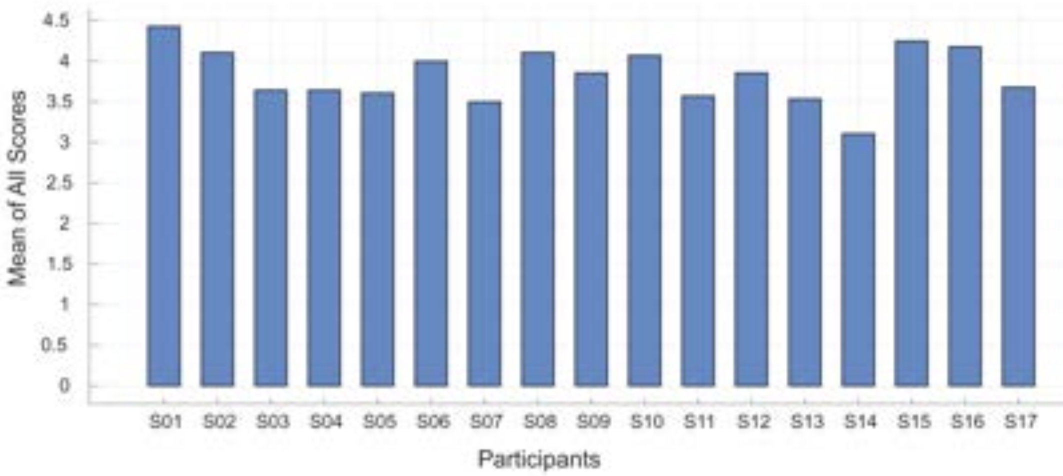

Figure 4.2 Distribution of mean CPAC scores across all participants

The average CPAC score pooled across for all participants is 3.83, ranging from a minimum of 1 to a maximum of 5. The mean scores among participants show an overall homogeneity ranging between 3.5 to 4.5 except for one participant.

As CPAC is composed of 6 sub-categories, we wanted to see how the scores are distributed across them. Figure 3.109 represents the normalized mean values of scores belonging to each category, with each dotrepresenting a single participant. As the minimum and maximum scores that can be reached in each category are different, we normalized each score within the respective category to be able to make a comparison across sub-categories. Thus, each dot shows, based on the score that the participant achieves, the percentage out of that sub-category, with 100% representing the highest score to be reached, respectively.

It can be seen in Figure 4.3 that flow, incubation, and metaphorical/analogical thinking show a more widespread tendency, compared to the scores in idea generation, idea manipulation, and imagery/sensory. Furthermore, while the median of normalized flow scores is the highest, the use of incubation in the creative process shows the lowest tendency among all.

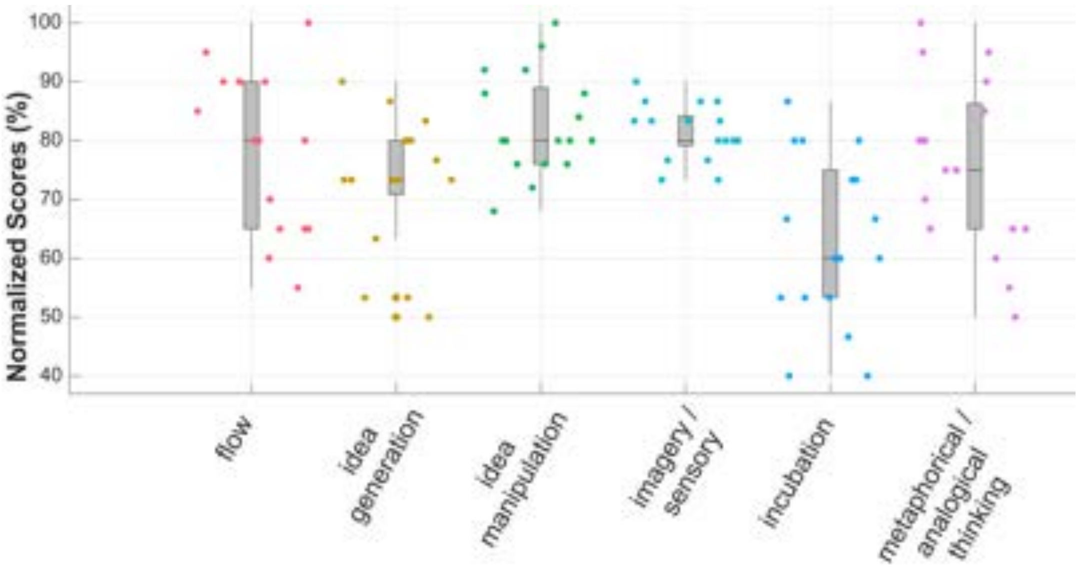

Figure 4.3 Distribution of CPAC scores among each sub-category. Colors represent sub-categories, while each dot is a single participant.

4.1.2 Self-report on Creative Trait Motivation

The second self-report questionnaire we used is the Creative Trait Motivation Scale (CTMS) focuses on creative engagement by evaluating individuals' intrinsic, extrinsic, and amotivation values. While the intrinsic motivation questions evaluate the motivation that drives individuals to engage in the creative process out of inherent interest, extrinsic motivation assesses the motivation driven by external rewards. On the other hand, motivation questions evaluate whether an individual lacks motivation for creating a product and disengaging from the process.

The CTMS makes use of a 1-7 Likert scale from ‘does not correspond at all’ to ‘corresponds exactly’. It covers intrinsic, extrinsic, and amotivation items together within a mixed order. The questions are then grouped into these three items. The test allows domain-specific instructions to be given to the tester, and the writers assess the test within art, science, and general domains. The writers suggest using the following introduction to the test: "Think about times when you have been creative in the [domain-specific instructions]. Using the scale below, indicate to what extent each of the following items presently corresponds to one of the reasons why you engage in [domain] creativity." Since the aim of applying this self-report in this study was to understand the effect of creative motivation of the subjects within the design domain, the brackets are filled as follows: "Think about times when you have been creative in the design. Using the scale below, indicate to what extent each of the following items presently corresponds to one of the reasons why you engage in design creativity."

As in CPAC values, we wanted to see how the mean values, pooled over all three categories (*intrinsic, extrinsic* and *amotivation*), across participant. Figure 4.6 below shows the mean values of all three scores for each participant. The average CTMS scores vary across participants, with a mean of 4.61 out of 7.

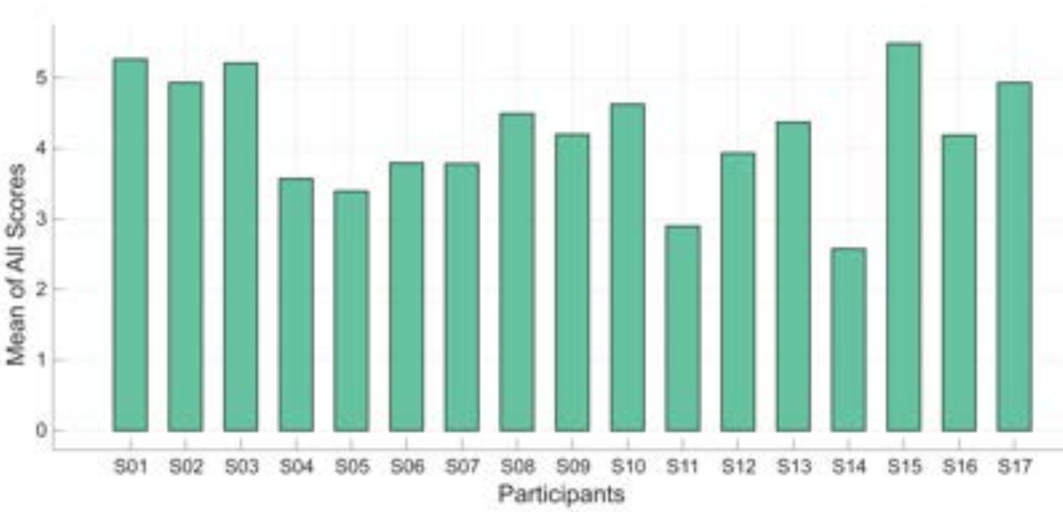

Figure 4.4 Distribution of mean scores across participants

Next, we wanted to see how each category is scored for each participant and varies across participants. To that end, we plotted the mean scores of each category (*intrinsic, extrinsic,* and *amotivation*) for each participant (Figure 4.7). The average score for *amotivation* is 3.22, for intrinsic motivation is 5.65, and for extrinsic motivation is 3.77.

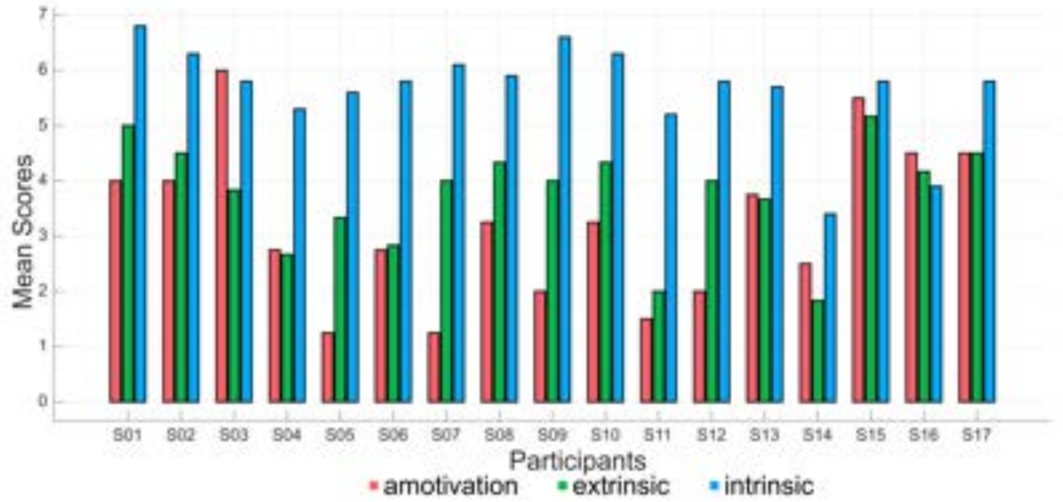

Figure 4.5 Distribution of three sub-categories *(extrinsic, intrinsic,* and *amotivation*, in green, red, and blue respectively) within and across participants.

While the intrinsic motivation scores outweigh 15 out of 17 participants, amotivation is the highest for 2 participants. Overall, it can be suggested that the majority of participants are guided by their intrinsic motivation.

4.2 Idea Sketches

The nature of data for creative product assessment was qualitative, forming with the drawings and notes of participants generated in Miro and documented as PDFs. The analysis was made in two-panel sessions with a jury composed of three raters. The jury consisted of the supervisor of the thesis, a design researcher from Aalborg University, and the researcher of this dissertation. This qualitative data was then analyzed using quantitative strategies to convert it into codes and numeric data, which could then be used in statistical analysis.

The FBS ontology that is developed by John Gero is chosen to code the sketches. It is a widely recognized and advanced categorization framework that can be applied across different design tasks and fields. It is chosen because the wide range of applicability of the coding scheme increases the study's replicability and also because the lack of standardization restricts the relevance of the findings (Kan and Gero, 2009). Then, to create a hierarchy and score them quantitatively, the genealogy tree technique developed by Shah et al. (2003) suggests the organization of organizing them into a hierarchy based on the significance of each function.

Figure 4.6 Miro board with all drawings made by all participants

The FBS Ontology

The Function, Behaviour, and Structure (FBS) is an ontology that offers a consistent framework that makes variances and similarities that might otherwise go unnoticed easier to determine. While function is the purpose of the object, behavior is what the object does to achieve its function, and the structure is the components that the object consists of (Gero and Kannengiesser, 2007). The ontology has been developed between 1984–1986 by Gero, presented in lectures and conferences and resulted in a paper (Gero, 1990). The process of applying FBS ontology starts with the segmentation and codification of data.

In order to conduct an FBS session, the sketches belonging to students, and their problem definitions (that are made in step 2) were organized to print. The photos were taken at the two sessions of FBS ontology, showing the prints of drawings.

Figure 4.7 Left: The researcher of the thesis and the supervisor, the first FBS session was conducted for sketches gathered on the water bottle problem on the 26th of June, 2024, at the faculty. Right: The visiting researcher and the supervisor, the second session was conducted for sketches gathered on the Bluetooth speaker problem on the 10th of July, 2024, at the faculty.

Also, a template to note down the keywords was prepared and given to the jury members during the analysis.

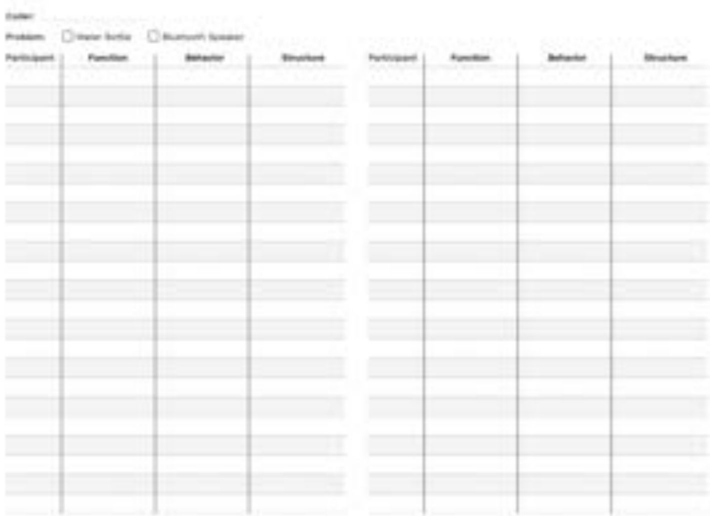

Figure 4.8 The FBS template to note down the derived keywords from the analysis sessions.

The Genealogy Tree

The genealogy tree technique proposes to decompose problems into key functions and construct a hierarchy according to the importance of each function.

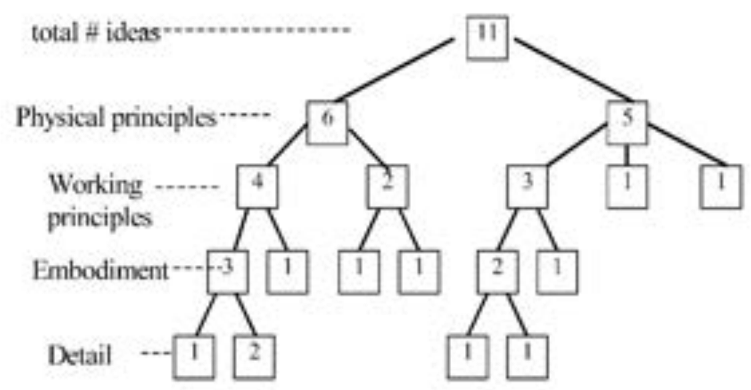

Figure 4.9 The genealogy tree model developed by Shah et al., 2003 (p.126)

At the top level, ideas are distinguished from one another by looking at the various physical principles that each idea uses to fulfill a particular purpose. At the second level, ideas share the same physical principle, but they are differentiated based on distinct operating principles. Ideas have distinct embodiments and details in the third and fourth levels, respectively. The number of ideas in each category at each level is carried by the nodes in the tree (Shah et al., 2003). The scores, then, are attained to each level in descending order.

The items deconstructed using the FBS ontology method were placed in the tree diagram. Four genealogy trees were formed to analyze the sketches:

c. Sketches from the water bottle's incubation condition
d. Sketches from the water bottle's control condition
e. Sketches from Bluetooth speaker's incubation condition
f. Sketches from Bluetooth speaker's control condition

Formulation of genealogy trees required other sessions apart from FBS analysis sessions and was made by two researchers. The first iterations were made with sticky notes, pen, and paper. As soon as the tree started to be formed, the notes were transferred into the Figjam workspace to formulate the trees. There were several iterations before the final versions were decided upon.

Figure 4.10 Genealogy tree of Bluetooth speaker's incubation condition, in Figjam.

After the trees were finalized, the data was transferred into Excel documents to prepare them for quantitative evaluation.

Figure 4.11 Excel documentation of genealogy tree of Bluetooth speaker's incubation condition

Instead of creating trees of each participant one by one, the data were prepared for a calculation made in C ++ with a code that can generate trees of participants with the given CSV sheet. For this phase, the researcher obtained support from Virani Başkurt, who is a programmer. The code that is generated for this study is shared online: https://github.com/nutsofyore/genealogy-tree-calculator

All keywords, participants, and levels are checked multiple times to ensure that no data has been lost or mixed during the manual data transfer to C++. Furthermore, in order to ensure that the formulas were correctly calculated, manual calculations on a couple of trees and participants were made, and the results were cross-checked.

Figure 4.12 Tree of the water bottle's incubation condition generated in C++

Calculation of Product Creativity

Then, Shah, Kulkarni, and Vargas-Hernandez's (2000) metrics of ideation effectiveness were used to score the sketches of each participant. The method is chosen to assess sketches because it relies on systematically evaluating the impact of various ideation methods. Although no specific ideation method is applied during the experiments, the method provides an outcome-based objective analysis and quantification of the qualitative data.

According to the guidelines, while the quantity and variety of sketches were evaluated based on the pool of all drawings generated by all participants, the quality and novelty of ideas were evaluated based on each participant's production according to this method. The degree and how they satisfy the solution space's design tasks are scored based on four metrics illustrated in the following table.

Table 4.1 Creativity metrics for design outputs (Shah, Kulkarni and Vargas-Hernandez, 2000)

Quantity	total number of ideas generated by a group when it uses a certain idea generation method
Quality	the feasibility of an idea and how close it comes to meeting the design specifications
Novelty	how unusual or unexpected an idea is as compared to other ideas
Variety	the explored solution space during the idea generation process

While novelty and variety metrics were calculated according to guidelines, quality metric is eliminated from the analysis, considering the time limitation of students during the experiments, which hinders the time to consider the feasibility or relevance of an idea. The quantity of ideas was calculated by basically counting how many different ideas were generated by each participant during steps 3 and 4.

Novelty is the degree to which an idea, solution, or product is different from what already exists. It is an important metric for determining the creativity of an idea. In this study, the approach of using all ideas generated by all participants as the universe of ideas has been taken instead of using the universe of ideas as a starting point. The lower the number of ideas generated for a function, the higher the novelty score since the number shows the rarity of the idea within the complete set of ideas (Shah, 2005).

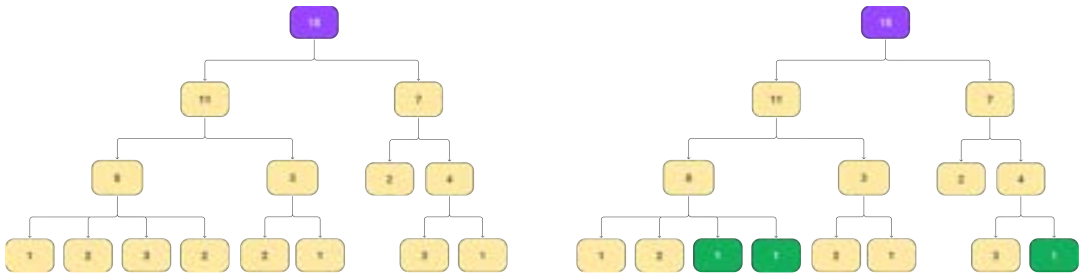

Figure 4.13 Left: Total tree with participant number belonging to each node. Right: Green leaves showing one participant's idea count.

Variety in idea generation refers to the range of different categories of ideas one can conceive. It indicates the multiple perspectives one can use to solve a problem. The number of branches in the tree indicates the variance in the ideas. The weights are assigned to measure variety in a way such that branches at the higher level get a higher value (Shah, 2005).

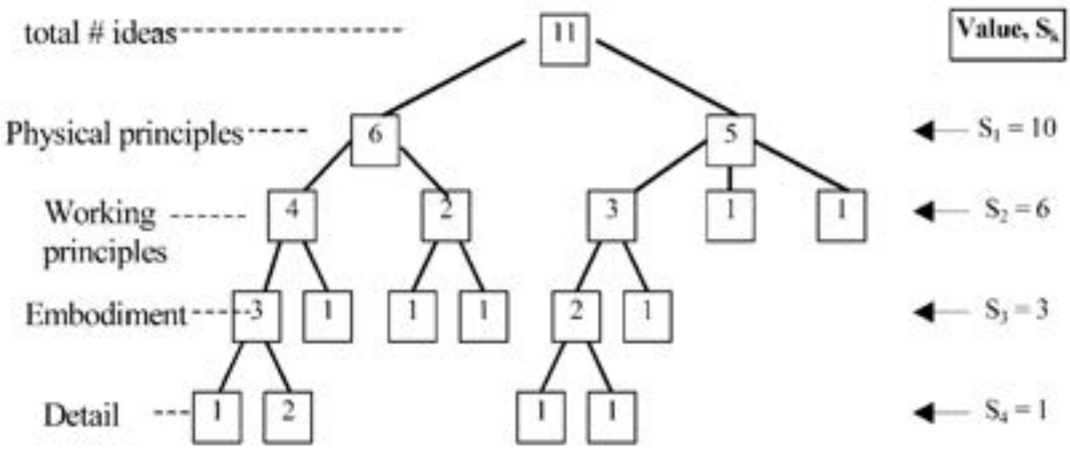

Figure 4.14 Genealogy tree with weights assigned to each level (Shah et al., 2003, p. 126)

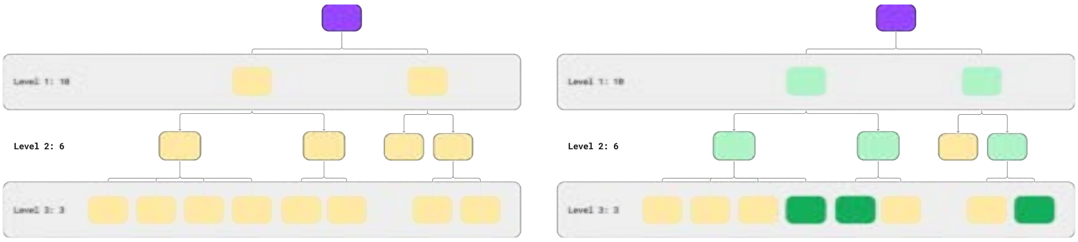

Figure 4.15 Left: Total tree with level weights. Right: Green nodes showing a tree of one participant.

Quantity is the overall number of ideas that an individual comes up with over a set period of time. The calculation of the quantity is made by counting the total number of ideas of each student throughout the process.

4.2.1 Codification of the Sketches

The sketches were categorized based on the problem. They were printed on paper and hung side by side. The FBS templates were used to note down the keywords. During the FBS analysis, we did not indicate which problem was solved within which condition to prevent bias. Three coders interpreted the sketches together with discussion, labeled behaviors and structures, and categorized them under functions to ease generating the tree.

Function is addressed as the purpose of an artifact. For example, the function of the body of a water bottle is to contain water. It is coded as the body under function to provide a concrete route in the following steps. Behavior is approached as the way the transition state achieves a function. We also address the interaction between product and person and the environment as behaviors. An example of a behavior of the lid of a water bottle is to turn (to open). The structure is addressed as the physical features, which can be a material, geometry, or dimensions. For instance, the structure of a body of water bottle can be cylindrical and plastic.

We made an enumeration for each keyword and corresponding sketch on drawings. Green color is used to code behaviors, while red color is used to code structures. The following list shows the filled version of the FBS template for two students.

S10 (previously coded as P14) is marked with a green dot to indicate that the participant belongs to the incubation condition after the coding phase was done.

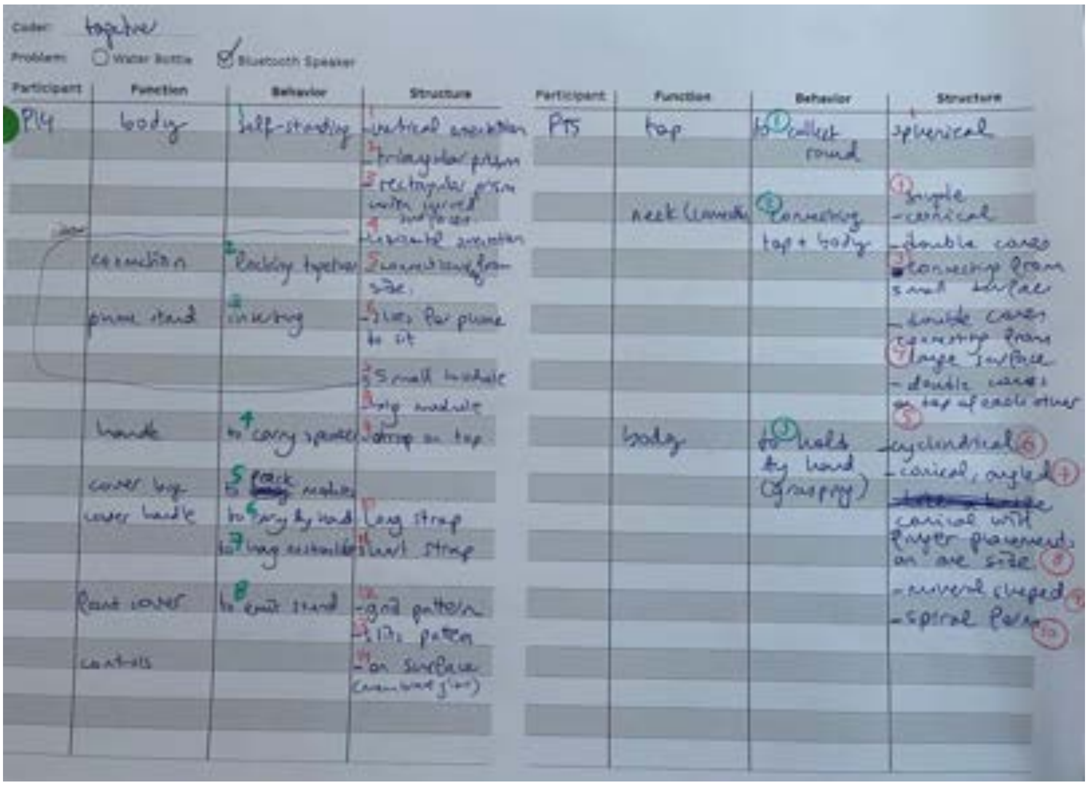

Figure 4.16 Filled FBS template

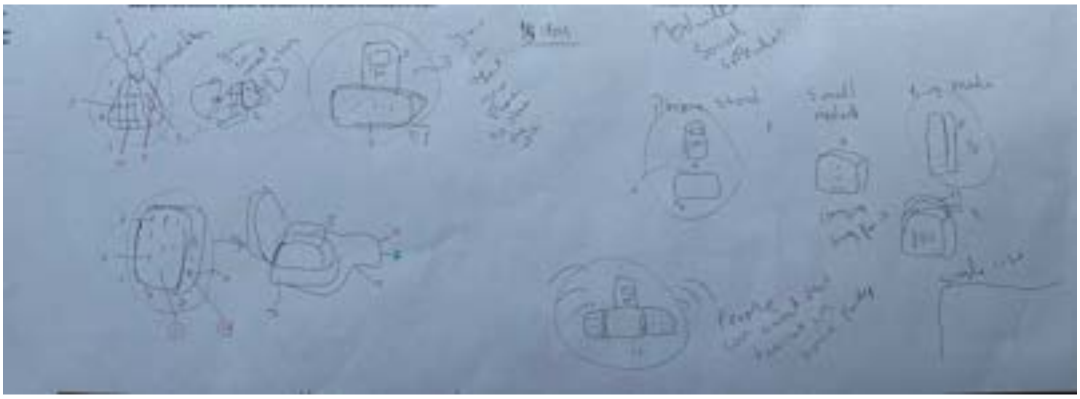

Figure 4.17 Color-coded sketch of a participant after the FBS session

The first session of FBS coding took approximately 4 hours, and we coded the sketches for the water bottle. The second session of FBS also took approximately 4 hours, and the sketches for the Bluetooth speaker were coded. The list of keywords was separated based on the experiment condition when transferring hardcopy lists to an Excel sheet.

4.2.1.1 Codification of Sketches of the Water Bottle

The main solution clouds emerged by codifying sketches of the water bottle's incubation and control conditions. 148 codes were derived in total, combining function, behavior, and structure. An example of the FBS structuring is a solid handle (structure) that is used to prove anti-rollover (function) by attaching its handles to the backpack (behavior). Although constructing this kind of relationship was impossible for each solution, the structure eased and systematized the following process of constructing the genealogy tree.

4.2.1.2 Codification of Sketches of the Bluetooth Speaker

The keywords emerged through the codification of sketches belonging to the Bluetooth speaker's incubation and control conditions were written down while considering the relation between function, behavior, and structure. 122 codes for the control condition and 143 codes for the incubation condition were derived in total. For example, the clips on the body (function) were to grasp (behavior) with a grippable section (structure). Also, not all keywords were used in the tree. For example, the aim of the sound output was to emit sound for all proposals. Therefore, there was no need to mention it specifically. We also changed some keywords to match the terminology. For example, we used "cover" in the initial analysis but changed it to "sound output" due to its appropriateness.

4.2.2 Categorization of the Sketches

The categorization of FBS codes was held in another session with two coders. We transferred the keywords into the Miro artboard and kept the similar keywords as they are in order not to skip or lose any information. Then, the sketches with notes on them from the FBS session were photographed and uploaded to the same artboard. The trees were finalized after several iterations. New categories were formed, or the unnecessary ones were eliminated during the iterations. In the end, two trees were generated for incubation and control conditions for both problems. The genealogy trees for the water bottle task (Appendix I for the control condition, Appendix J for the incubation condition) and for the Bluetooth speaker task (Appendix K for the control condition, Appendix L for the incubation condition) are provided in the appendix.

4.2.2.1 Categorization of Water Bottle Sketches

The sketches of water bottles reveal several similar categories for both conditions. They formed solution clouds of body, components, and integration. While the total number of levels for the control condition was 7, it was 8 for the incubation condition.

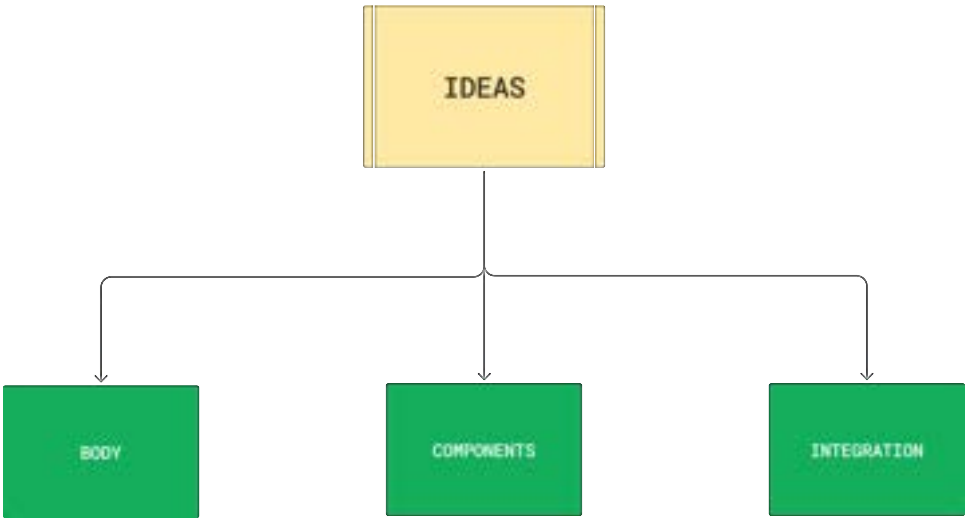

Figure 4.18 The highest level of themes

The themes at the highest levels then branched into different categories that are diversified between incubation and control conditions.

4.2.2.1.1 Tree of Incubation Condition

The tree of the incubation condition contains 69 different ideas in total.

Theme of body

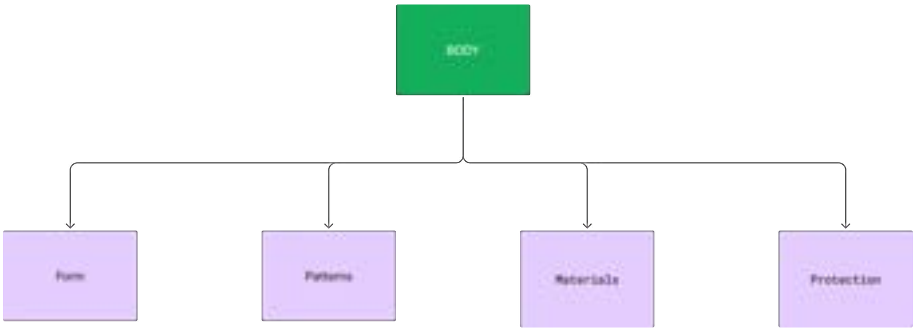

Figure 4.19 Theme of body

The category of form is divided into two sub-categories: rigid and flexible.

The sub-category of rigid is divided into two based on the form.

The amorphous forms are either asymmetrical or symmetrical. The cylindrical forms are either with a handle or without a handle. Those that have a handle are mugs, kettles, beer glasses, or a cylindrical form with ear-like bumps to hold. Those that are without handles are curvy, straight, or standard shape. Curvy ones are either dumbbell-shaped or hourglass-shaped. Straight ones are slim/thin, long, or standard. Sculpted ones are either asymmetrically sculpted or symmetrically sculpted.

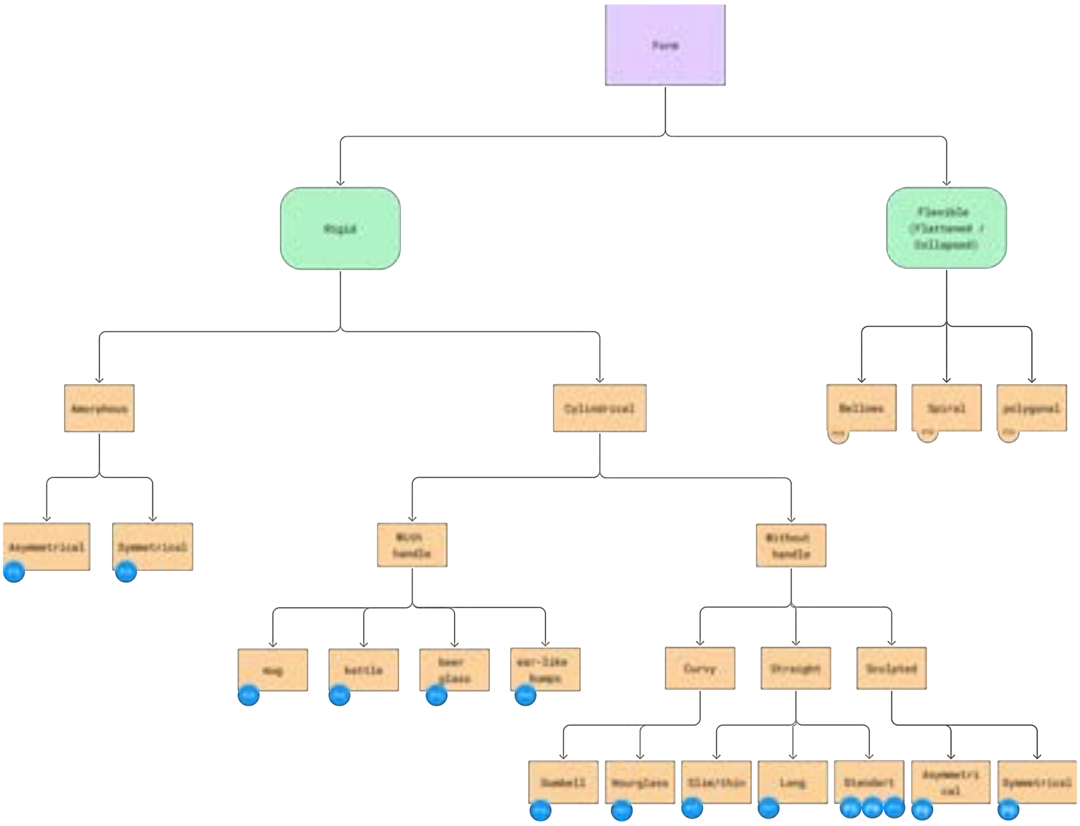

Figure 4.20 Branches of the category of form

The sub-category of flexible is divided into three based on the form, which are bellows, spiral, or polygonal.

Figure 4.21 Different sketch examples for the form category. Left: Rigid body with a handle. Second from left: Asymmetrically sculpted body. Third from left: Cylindrical rigid body. Right: Beerglass form.

The category of patterns is separated into three sub-categories: Form, graphical, and no pattern. While form is used for pattern suggestions using body shape to create the patterns, graphical suggestions use 2D graphics to create the pattern.

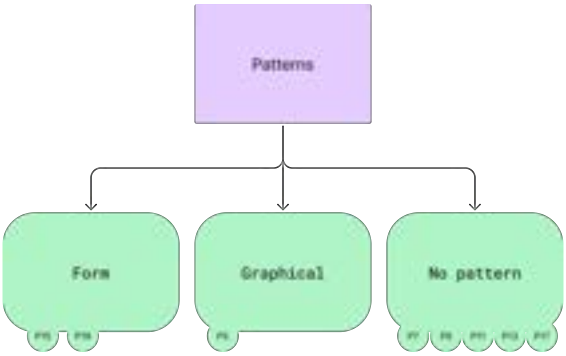

Figure 4.22 Branches of the category of patterns

The category of materials is divided into two sub-categories: steel and recyclable plastic.

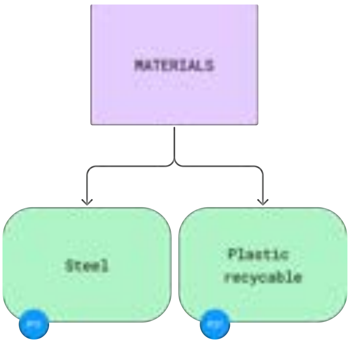

Figure 4.23 Branches of the category of materials

The category of protection is divided into two sub-categories: impact-resistance and double-wall insulation.

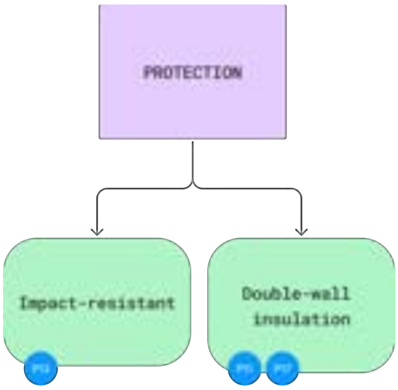

Figure 4.24 Branches of the category of protection

Theme of Components

The second theme is formed with the components of a water bottle. The theme is divided into four categories: handle, spout, lid, and fabric cover.

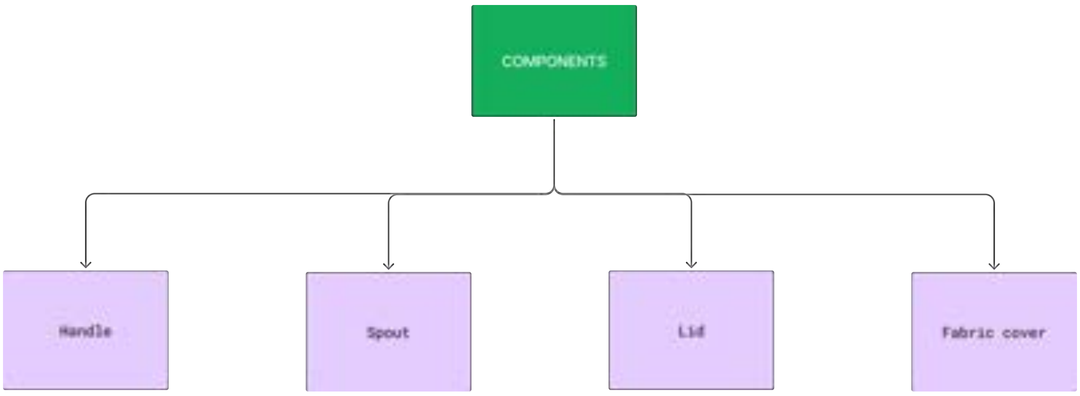

Figure 4.25 Branches of the category of components

The category of handle is divided into two sub-categories: form and anti-rollover (Figure 4.28).

The sub-category of form is separated into two. The rigid handle forms that are open-ended or closed-ended. Open-ended ones are either located on one side, or on both sides. The rigid handle forms that are closed are either formed with an additional material or formed with a hole in the body.

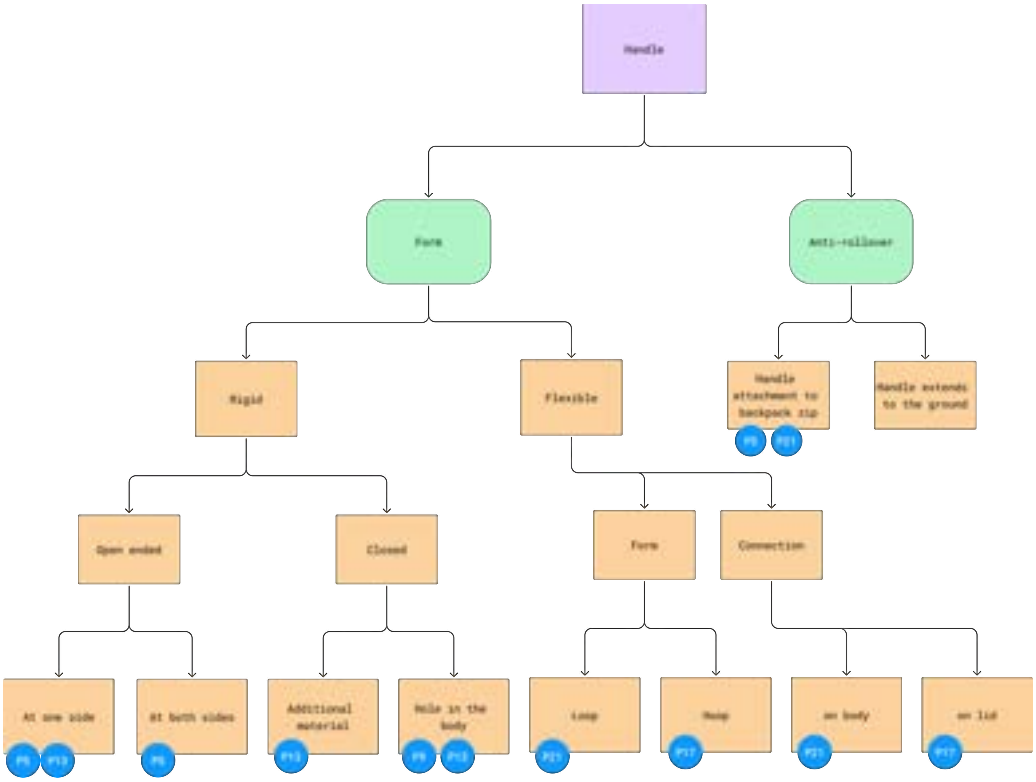

Figure 4.26 Branches of the category of handle

The flexible handles are separated into two parts: either loop formed or hoop formed. The flexible handles are also divided into two based on connection type, which is either on the body or on the lid. The handles that have anti-rollover protection are fulfilled with either; handle attachment to the backpack zip, or handle extends to the ground.

Figure 4.27 Sketch examples for handle solutions. Left: Hoop-formed handles. Two in the middle: Loop-formed handles. Right: Open-ended handle at one side.

The spout solutions contain two different sub-categories: central fixed short spout and central-fixed long spout.

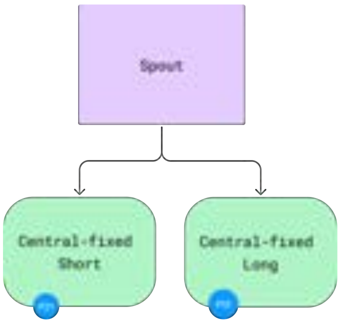

Figure 4.28 Branches of the category of spout

The category of lid is separated into three: connection with body, form and being leak-proof.

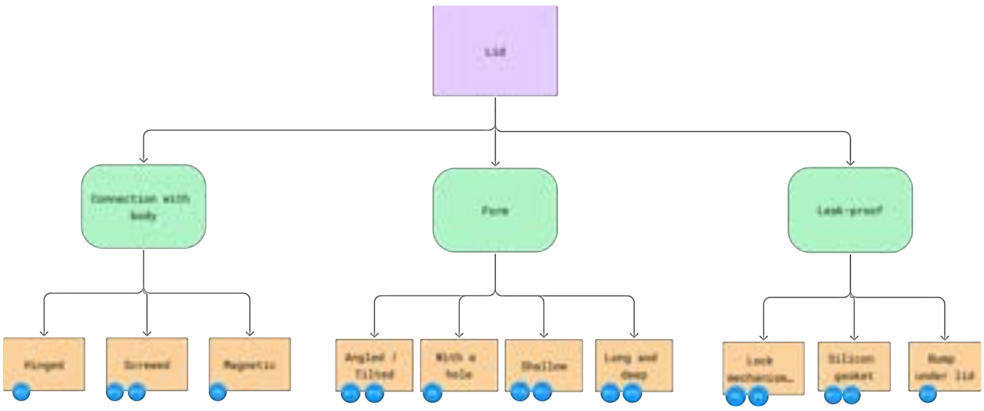

Figure 4.29 Branches of the category of lid

Connection with the body offers solutions for different connections, which are having a hinge, having a screw, or having a magnet. The sub-category form contains four different solutions: angled/ tilted, lid with a hole, shallow, or long and deep lids. The sub-category leak-proof contains ideas about providing leak-proofness with different solutions: the lock mechanism on the side, a silicon gasket between the lid and neck, or a bump under the lid.

The category of cover only has one solution offered by one student, which is for providing an attachment to various surfaces.

Theme of Integration

The theme of integration offers ideas for integrating water bottles with the backpack. It contains two sub-categories: the water bottles inserted in the backpack pocket and connected to the backpack.

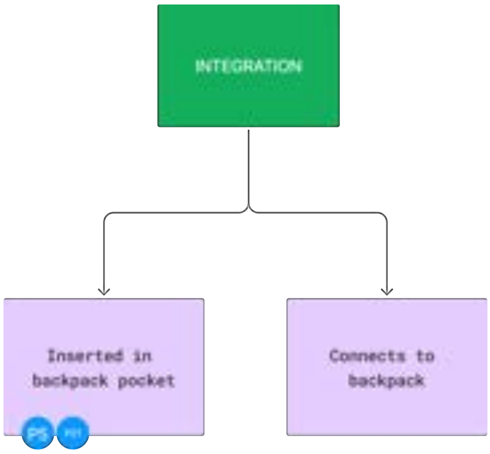

Figure 4.30 Branches of the category of integration

4.2.2.1.2 Tree of Control Condition

The tree of the control condition contains ideas about body, components and integration.

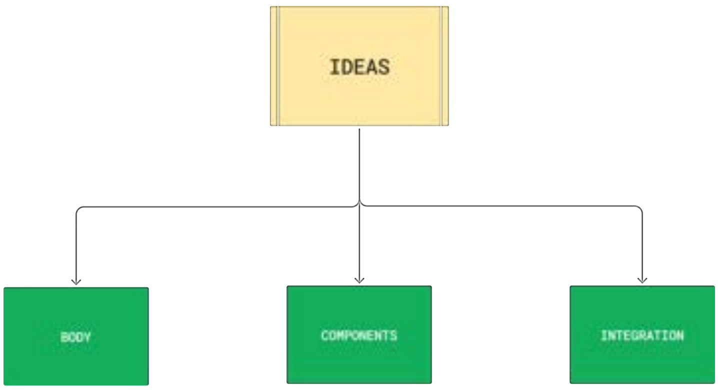

Figure 4.31 The highest level of tree

Theme of Body

The theme of the body contains five different categories, which are form, orientation, labels, protection, and materials.

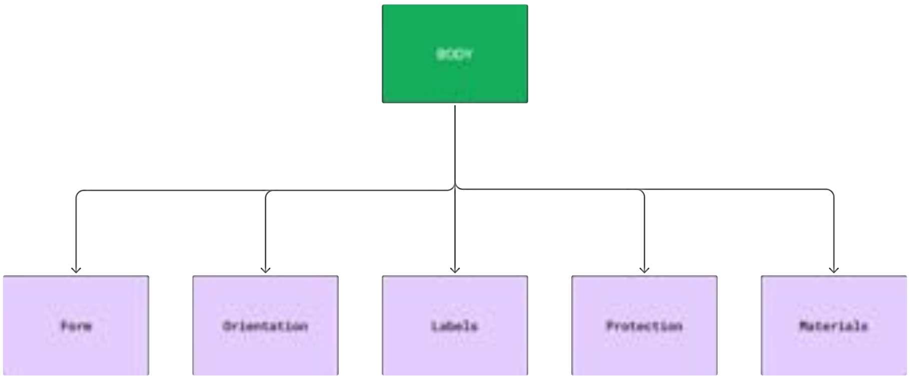

Figure 4.32 Branches of the theme of body

The category of form is divided into two sub-categories: rigid and flexible with bellows.

Solutions for rigid forms are D-shaped conical symmetrical amorphous, or cylindrical. D-shaped ones are either asymmetrically sculpted or straight. Cylindrical ones are: Dumbbell forms that are either straight or curvy, conical hourglass forms, asymmetrically sculpted form, curved axis form or straight form.

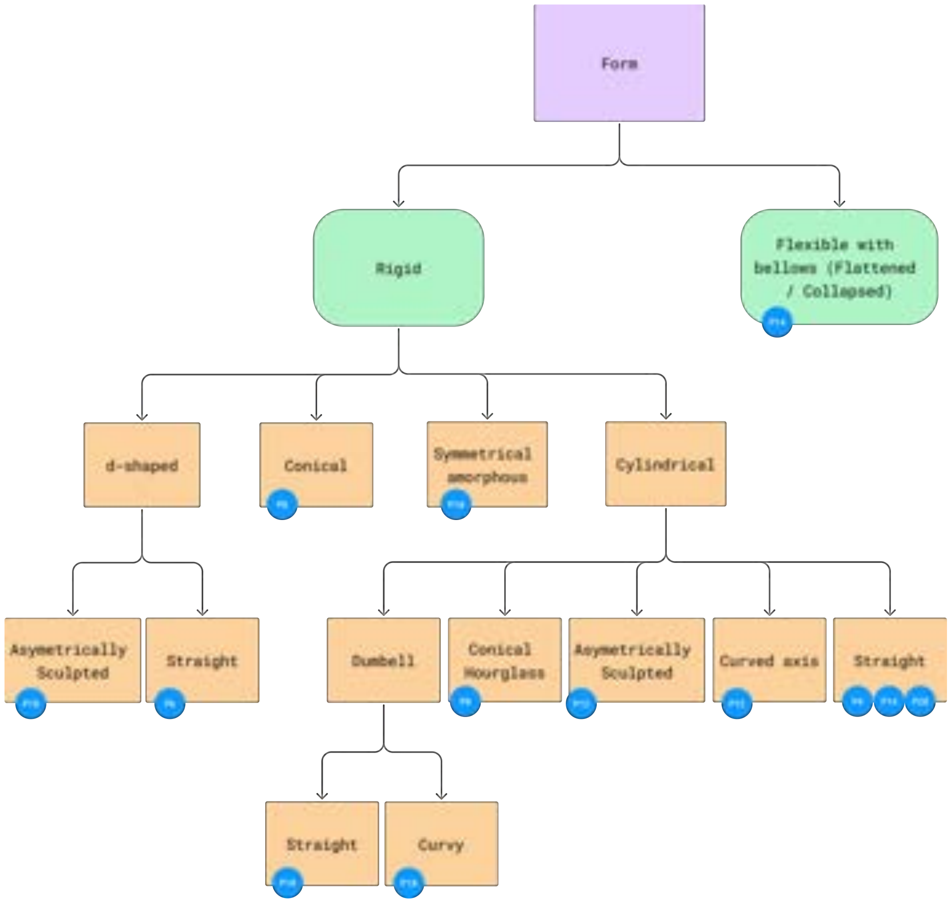

Figure 4.33 Branches of the category of form

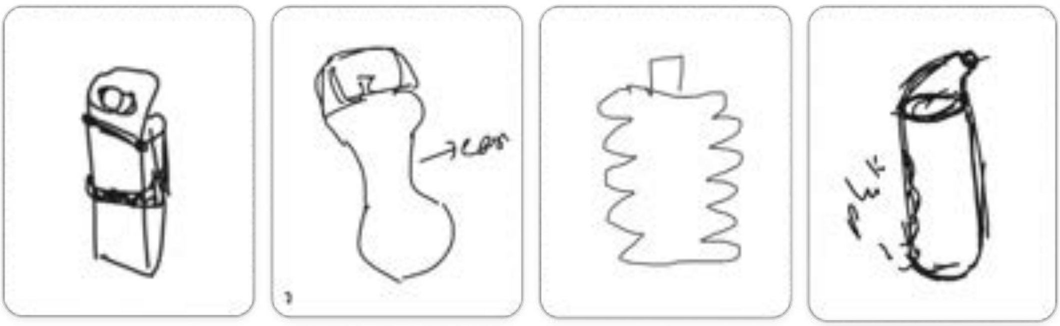

Figure 4.34 Sketch examples for different form solutions. Left: D-shaped. Second from left: Dumbbell shaped. Third from left: Flexible body with bellows. Right: Cylindrical.

The category of orientation is divided into two sub-categories: right side up and upside down.

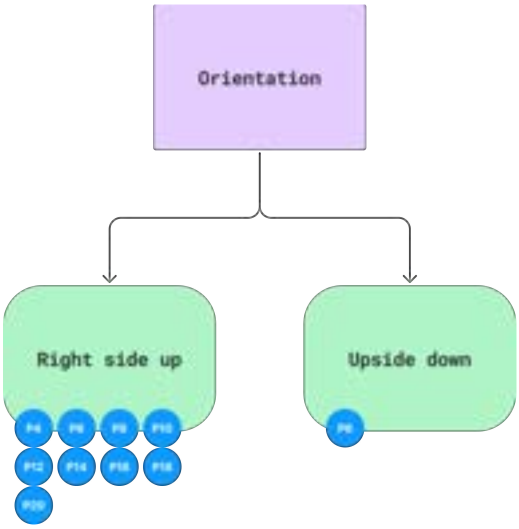

Figure 4.35 Branches of the category of orientation

The category of labels contains one idea belonging to one participant, which suggests showing the amount or level of water in the bottle.

The category of materials is divided into four sub-categories: metal, composite, biodegradable, and plastic.

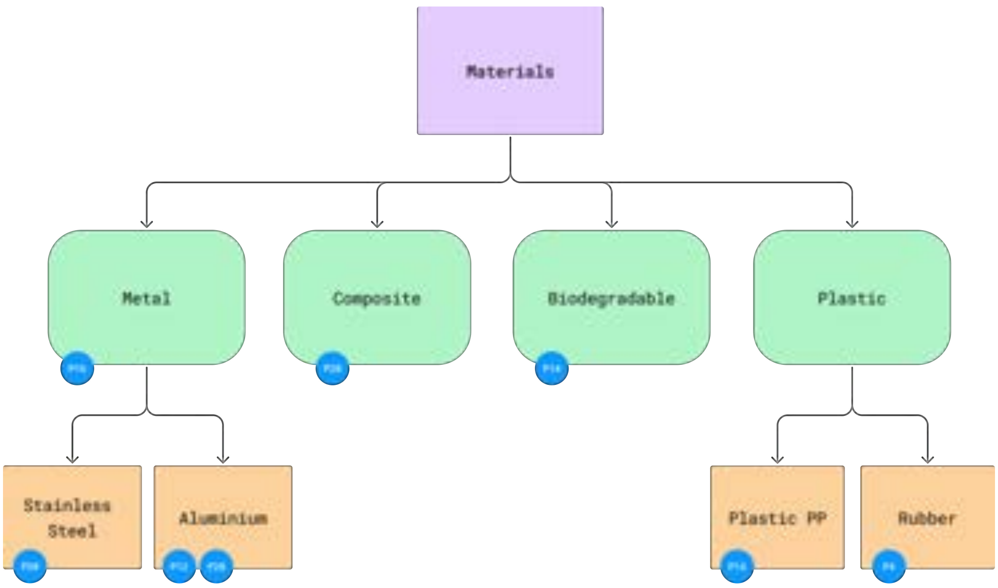

Figure 4.36 Branches of the category of materials

The materials are metal, either stainless steel or aluminum. The plastics are either PP plastic or rubber.

The category of protection is divided into two sub-categories.

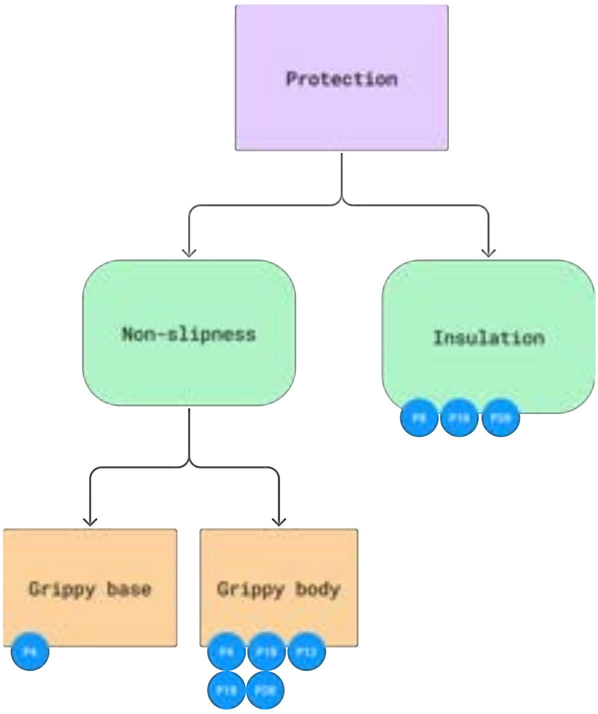

Figure 4.37 Branches of the category of protection

The protection for non-slipperiness is provided with either grippy base, or grippy body.

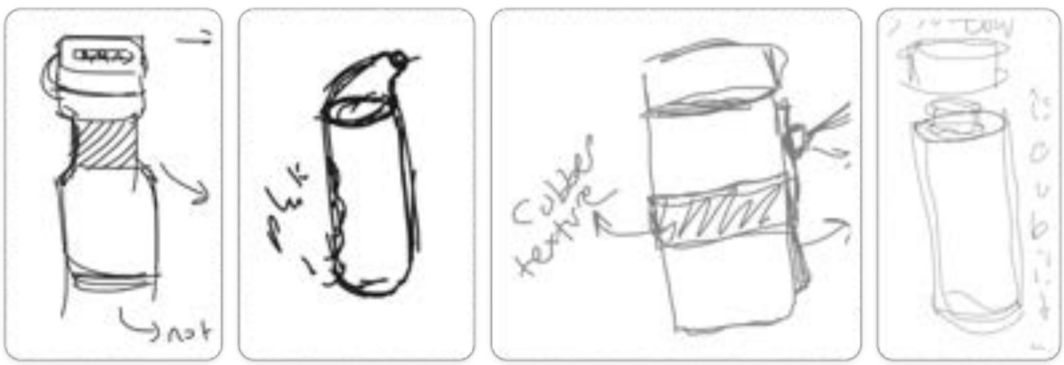

Figure 4.38 Sketch examples for protection ideas. First three sketches offer ideas about non-slipperiness with a grippy body. Sketch on the right represents a solution for insulation with a double-walled body.

Theme of Components

The theme of components contains four different categories: handle, spout, lid and cover.

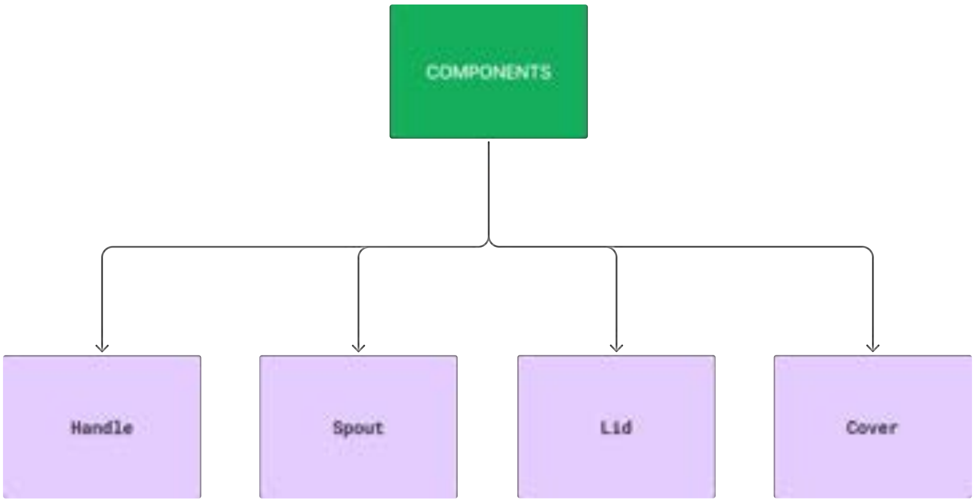

Figure 4.39 Branches of the theme of components

The category of handle is divided into two sub-categories, which are form and connection.

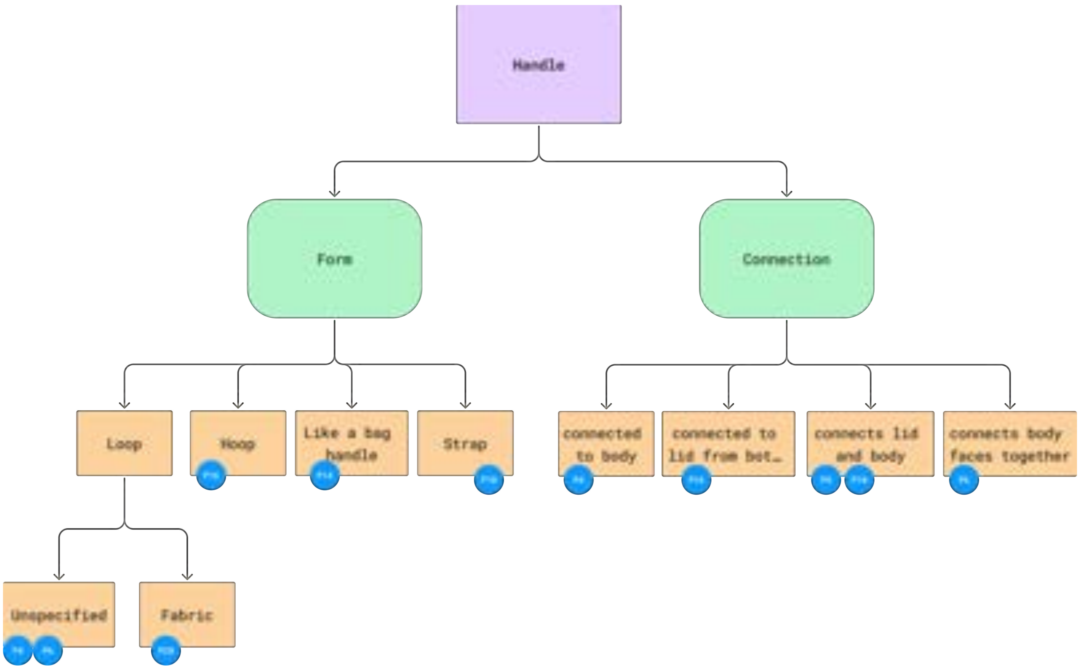

Figure 4.40 Branches of the category of handle

The solutions of the form of the handle are loop, hoop, like a bag handle or strap. Loop forms have two material suggestions, which are an unspecified material or a fabric.

The solutions of connection of handle include a handle connected to the body, a handle connected to lid from bottom, handles connect lid and body, or body faces together.

The category of spout contains ideas belonging to two sub-categories: foldable and central-fixed short.

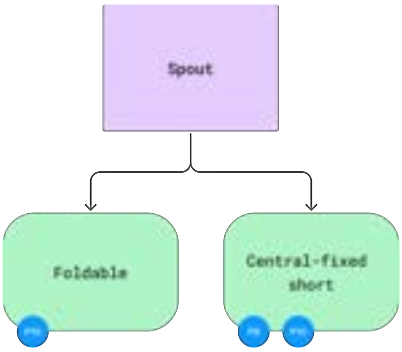

Figure 4.41 Branches of the category of spout

The category of the lid contains solutions under three sub-categories: connection with the body, a form of the lid, and leak-proof protection.

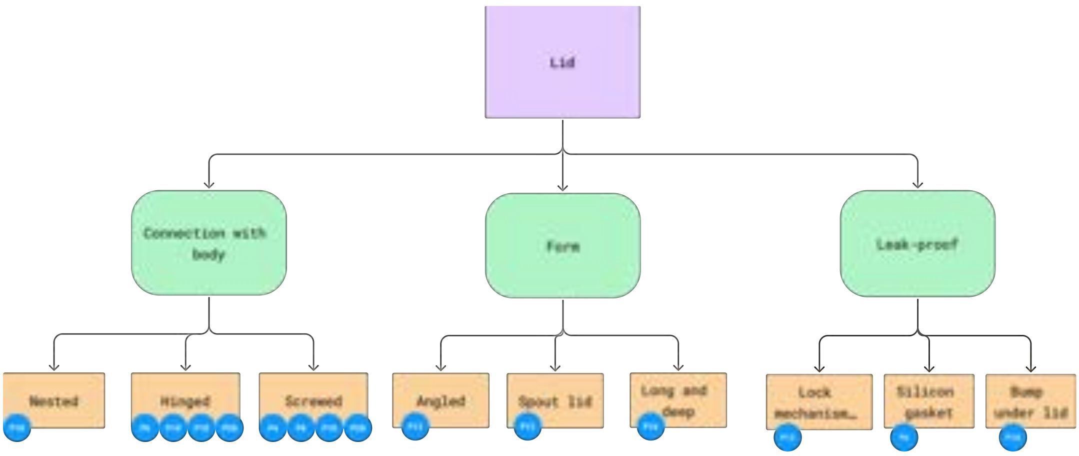

Figure 4.42 Branches of the category of lid

Solutions for connection with the body are nested, hinged, or screwed.

Form solutions for the lids are angled, spout lid, or long and deep.

Leak-proofness is provided with a lock mechanism on top, a silicon gasket, or a bump under the lid.

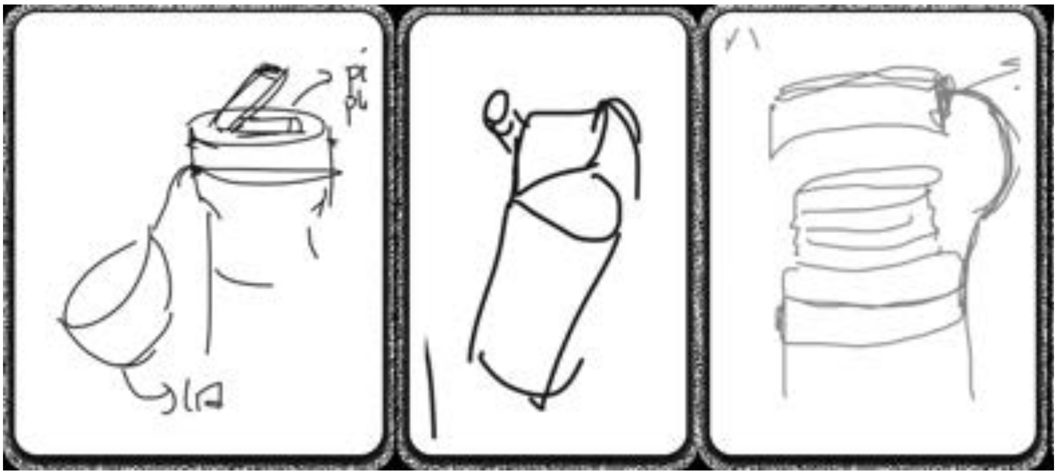

Figure 4.43 Sketch examples for different lid solutions. Left: Lid connected to body. Second from left: Hinged lid that sways open to one side. Right: Screwed lid.

The category of cover is divided into three sub-categories: coat cover, multiple-faced cover, or faces held with strap cover.

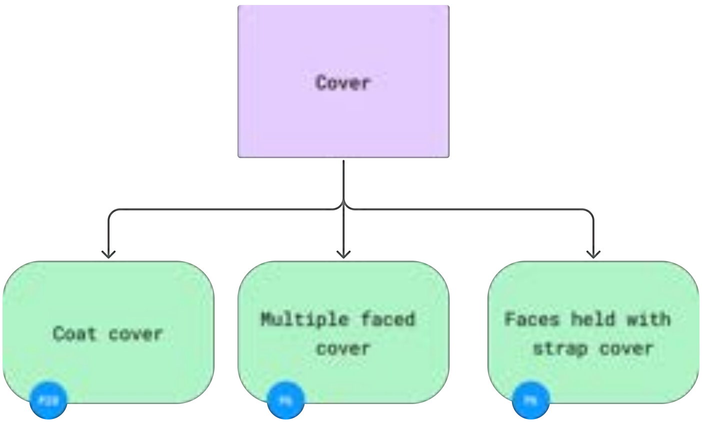

Figure 4.44 Branches of the category of cover

Theme of Integration

The theme of integration contains solutions for water bottles that are either inserted in the backpack pocket or connected to the backpack's side with its straps.

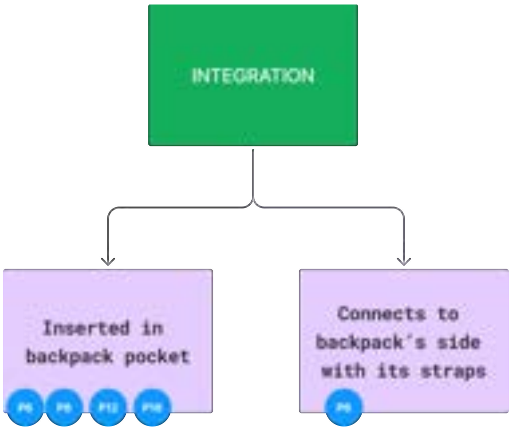

Figure 4.45 Branches of the theme of integration

4.2.2.2 Categorization of Sketches of the Bluetooth Speaker

The sketches reveal several similar categories for both conditions. They formed solution clouds of body, components, and integration. While the total number of levels for the control condition was 8, it was 7 for the incubation condition. However, the variety in the incubation condition tree was greater, and the variance under different categories showed a balanced distribution as compared to the control condition.

Figure 4.46 Top: Genealogy tree of control condition. Bottom: Genealogy tree of incubation condition

4.2.2.2.1 Tree of Incubation Condition

The tree of the incubation condition contains three themes, which are body, components, and integration.

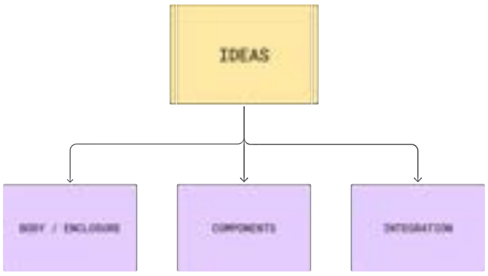

Figure 4.47 The highest level of themes

Theme of Body

The theme of the body is divided into four categories: form, dimensions, colors, and orientation.

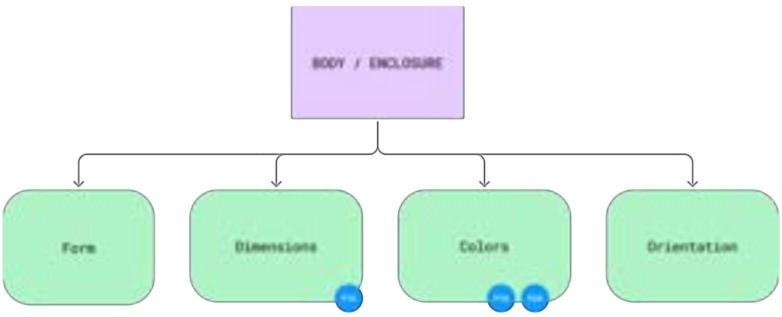

Figure 4.48 Branches of the category of body

The category of form is divided into two sub-categories: rigid and flexible.

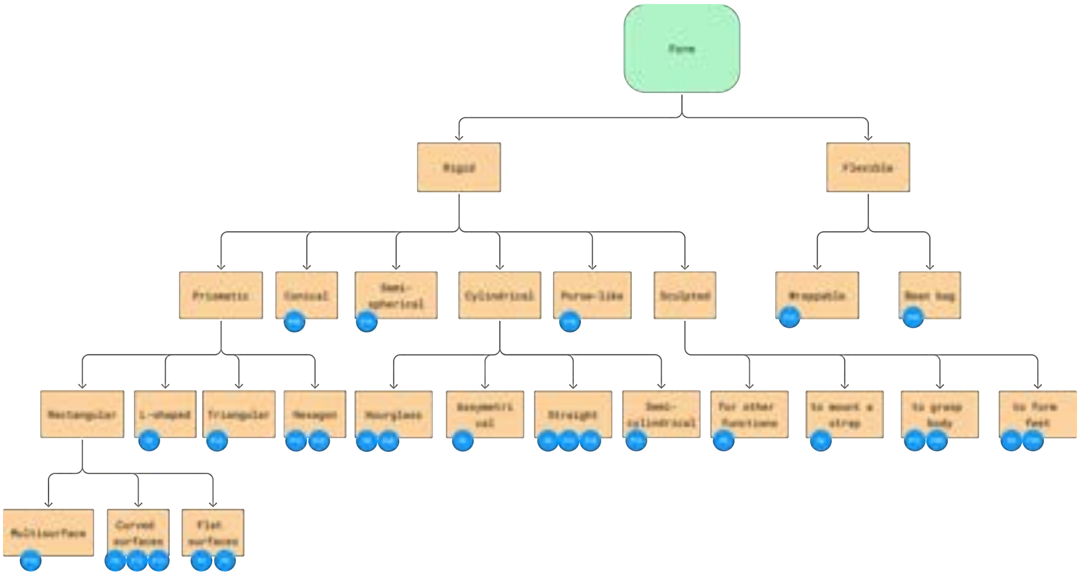

Figure 4.49 Branches of the category of form

Rigid forms are conical, semi-spherical, purse-like, prismatic, sculpted or cylindrical. Prismatic ones are with a rectangular shape, an L-shape, a triangular shape, or a hexagonal shape. Rectangular shape suggestions are having multi-surfaces, curved surfaces, or flat surfaces. Cylindrical ones have an hourglass shape, asymmetrical shape, straight shape, or semi-cylindrical shape. Sculpted body forms are designed for other functions, such as mounting a strap, grasping the body, or forming feet. Flexible forms are either wrappable or as a bean bag.

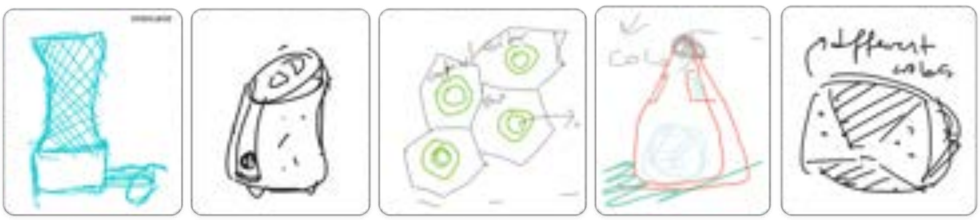

Figure 4.50 Sketch examples for different form solutions. Left: Hourglass. Second from left: Sculpted to form feet. Third from left: Hexagon. Fourth from left: Bean bag. Right: Purse-like.

The category of orientation is divided into four sub-categories: self-standing, vertical orientation, horizontal orientation, and hangable.

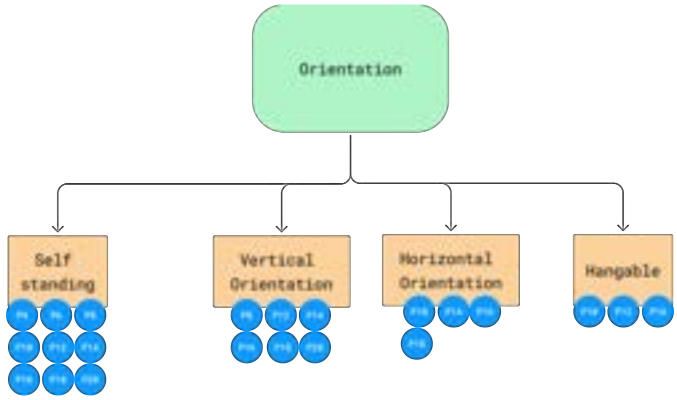

Figure 4.51 Branches of the category of orientation

Theme of Components

The theme of components contains seven categories, which are sound output, battery, charging port, buttons, displays, handle and carrying case.

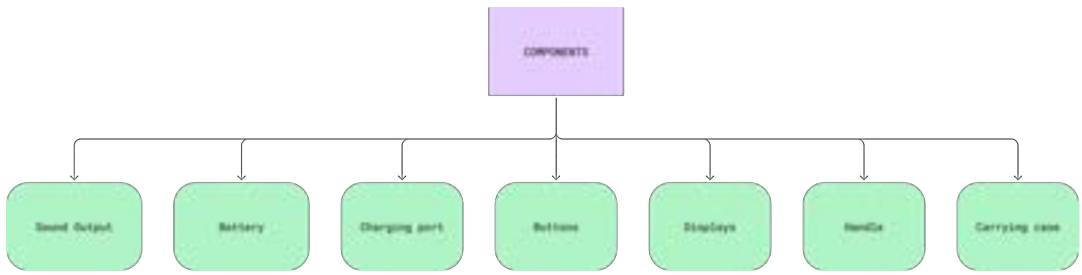

Figure 4.52 Branches of the category of components

The category of sound output is divided into three sub-categories: all around with grid pattern, at front face, and at top and bottom.

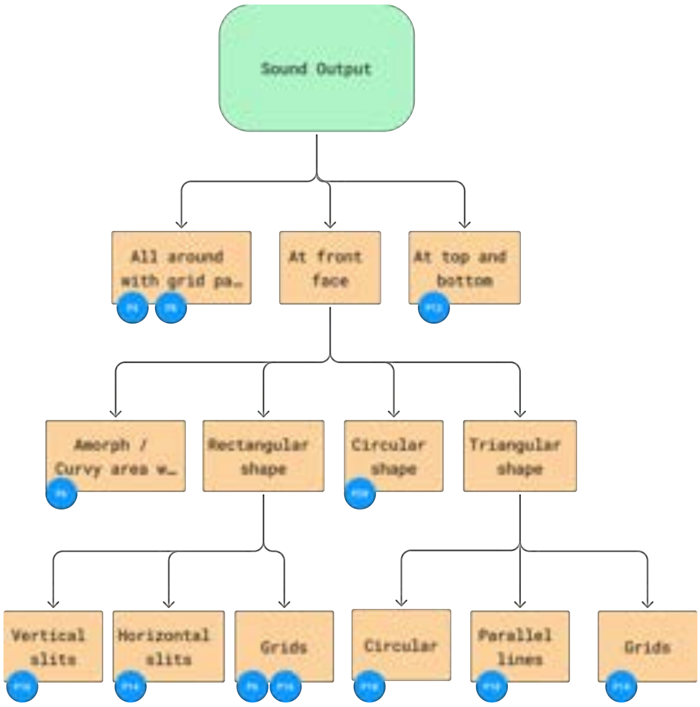

Figure 4.53 Branches of the category of sound output

The sound outputs at the front face are: amorph / curvy area with dotted pattern, circular shape, rectangular shape or triangular shape. While rectangular shapes have vertical slits, horizontal slits, or grids, triangular shapes have circular patterns, parallel lines, or grids.

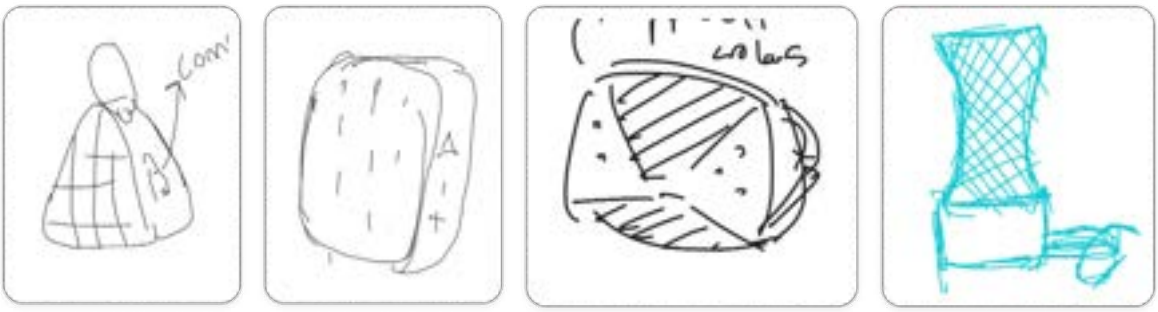

Figure 4.54 Sketch examples for sound output solutions. From left to right: Grids, Vertical slits, horizontal slits, and grids.

The category of buttons is divided into three sub-categories: form, function, and solution.

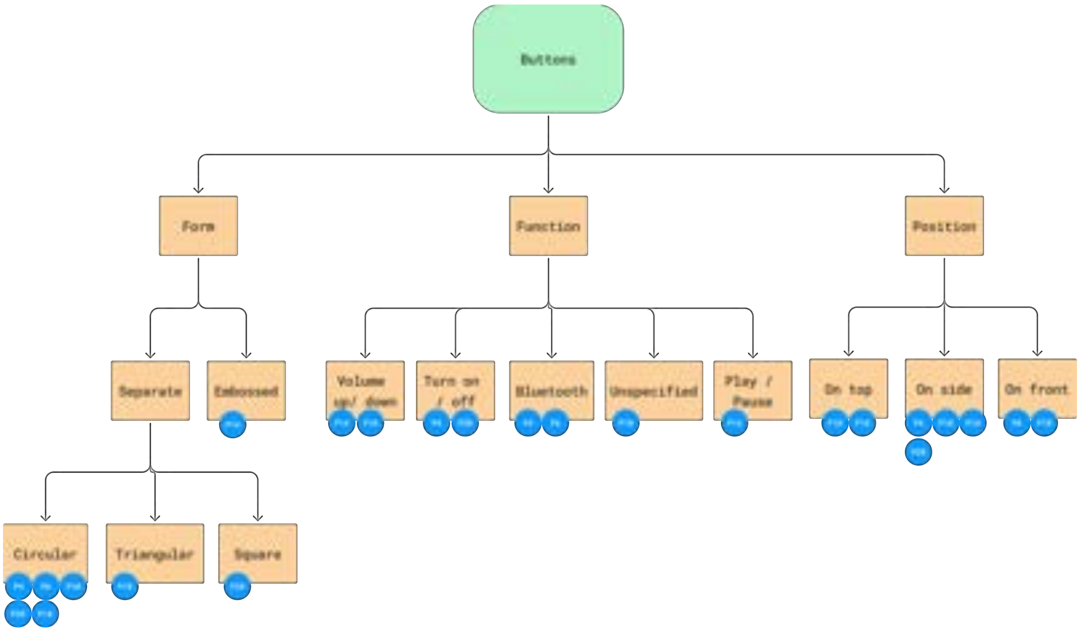

Figure 4.55 Branches of the category of buttons

Button forms are either separated or embossed. Separated ones have a circular shape, a triangular shape or a square shape.

The functions of buttons are diverse: to volume up/ down, to turn on/ off, to connect with Bluetooth, to play/pause, or unspecified.

Buttons are positioned on top, on side, or on feet.

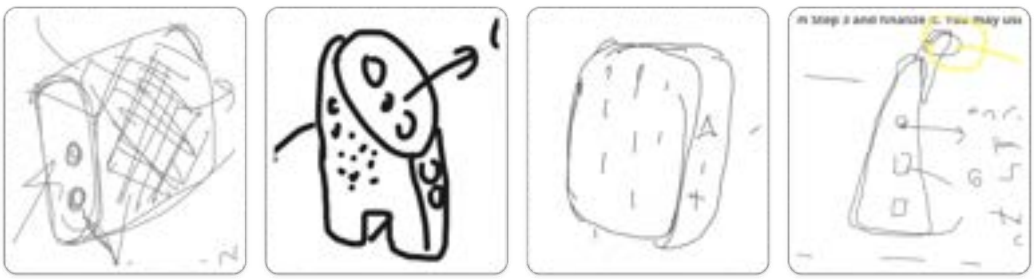

Figure 4.56 Sketch examples for different button forms and placements. From left to right: Separate and circular buttons on the side, separate and circular buttons on front, embossed buttons for play/ pause and volume up/ down on side, rectangular buttons on side.

The category of displays includes solutions offering a touchscreen or a screen.

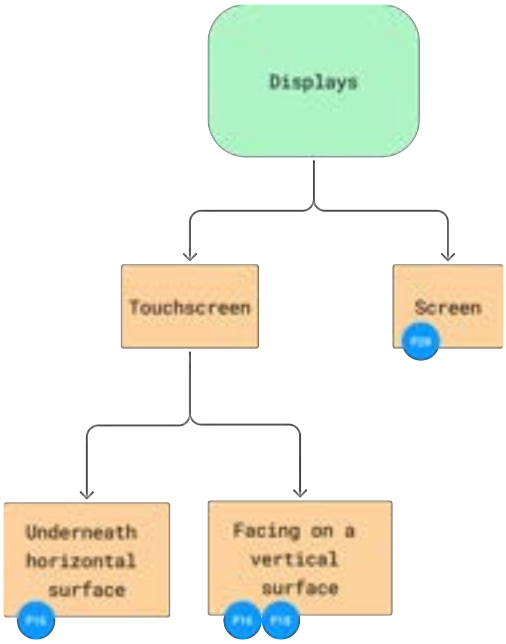

Figure 4.57 Branches of the category of displays

Touchscreen displays are positioned either underneath horizontal surface, or facing on a vertical surface.

The category of handle is divided into two sub-categories: flexible and rigid.

Flexible handles are rope, loops to insert on a belt, a body turning into a handle, or straps specialized for other functions. These straps are to hang the speaker on a backpack handle, hang it on the shoulder, insert a hand into it, insert it on a belt, or attach it. The ones to insert the hand are flat handles with sculpted bodies, edgy and rubber handles, or curvy handles with grippable sections. Solutions to insert it on a belt are either with a magnet or mechanical fasteners.

Ones with a body that can turn into a handle are either wrappable on a bag strap or on a bike frame.

Rigid handles are hook-shaped, clips for various functions, or are mounted. Clips are for attaching speakers on a belt the from top or hanging on a one side.

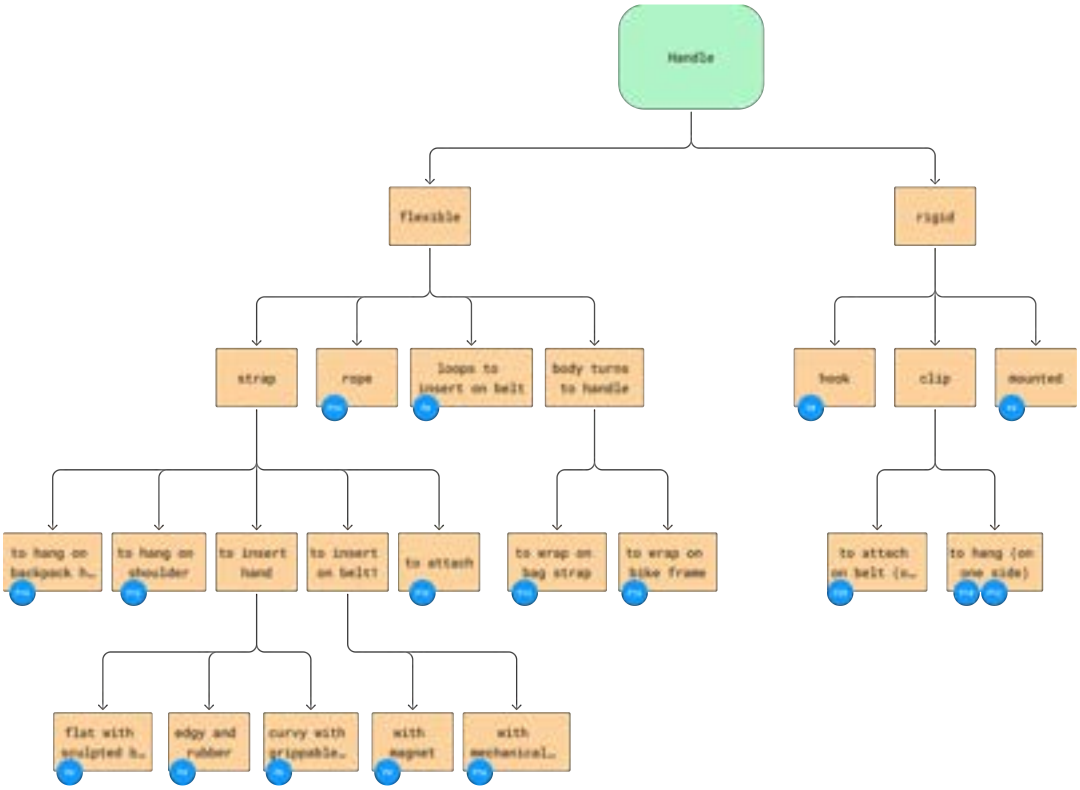

Figure 4.58 Branches of the category of handle

Figure 4.59 Sketch examples for handle solutions. Left. Edgy and rubber strap. Second from left: Flat strap with sculpted body. Third from left: The body of the speaker turns to the handle to wrap on a bag strap. Right: Clip to hang.

The category of carrying cases is subdivided into two: cases to pack modules and to carry.

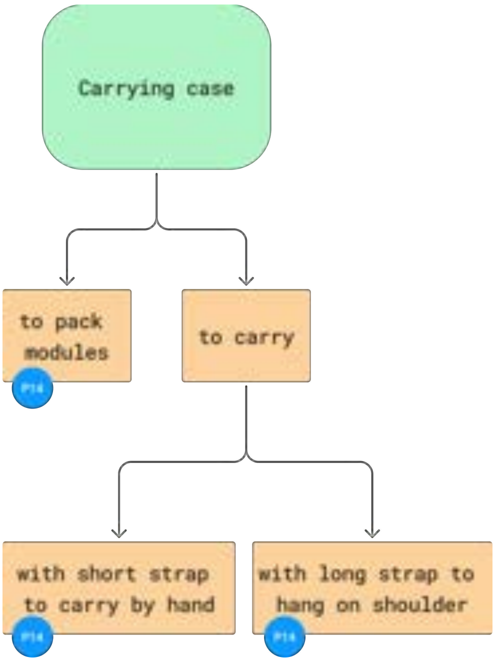

Figure 4.60 Branches of the category of carrying case

Carrying cases to carry are either with a short strap to carry by the hand, or a long strap to hang on a shoulder.

Theme of Integration

The theme of integration is divided into two sub-categories: interaction with other products and configuration.

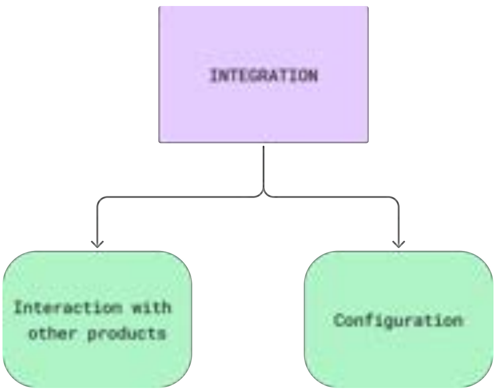

Figure 4.61 Branches of the category of integration

The category of interaction with other products contains three sub-categories: pairing, phone docking station and collecting sound from different instruments.

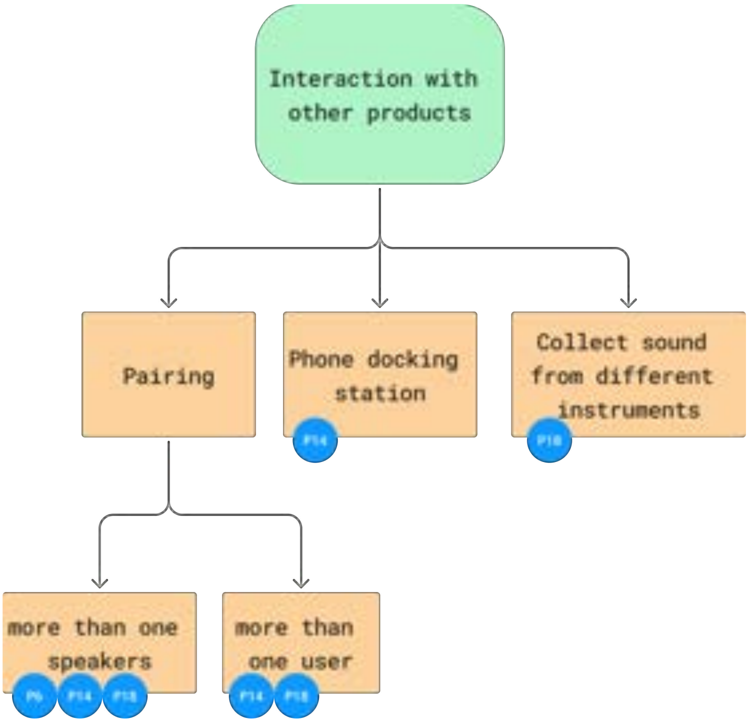

Figure 4.62 Branches of the category of interaction with other products

Pairing interactions pair speakers with either more than one speaker or more than one user.

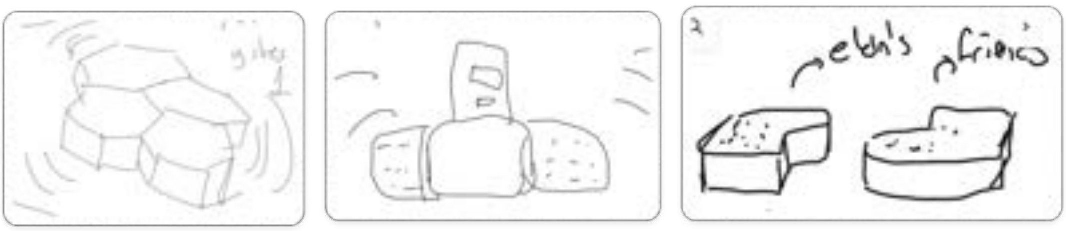

Figure 4.63 Sketch examples for interaction with other products. Left: Pairing more than one speaker and connecting sound from different instruments. Middle: Phone docking station. Right: Connecting more than one speaker with more than one person.

The category of configuration is divided into four sub-categories: Male-female configuration, connection slots at the side, pins, and side-by-side configuration.

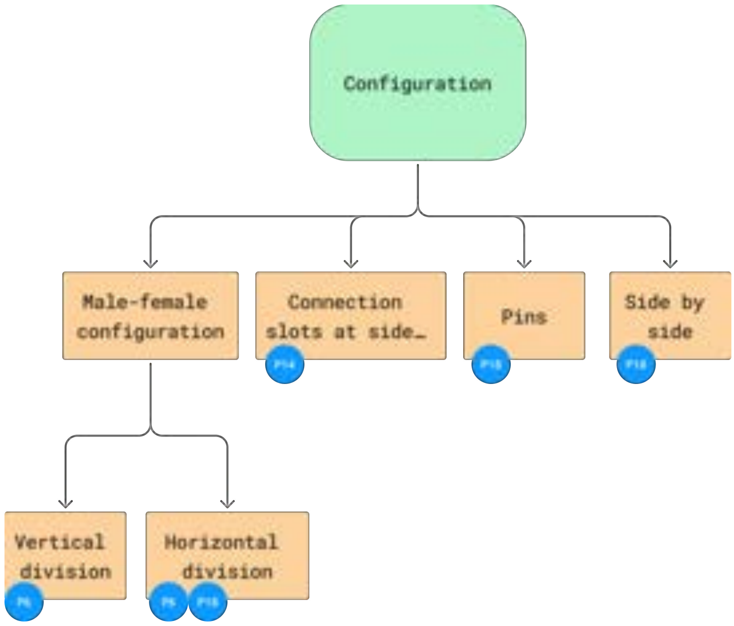

Figure 4.64 Branches of the category of configuration

Male-female configurations are either designed with a vertical division or a horizontal division.

4.2.2.2.2 Tree of Control Condition

The tree of control conditions includes the same three themes as the incubation condition, which are body/ enclosure, components, and integration.

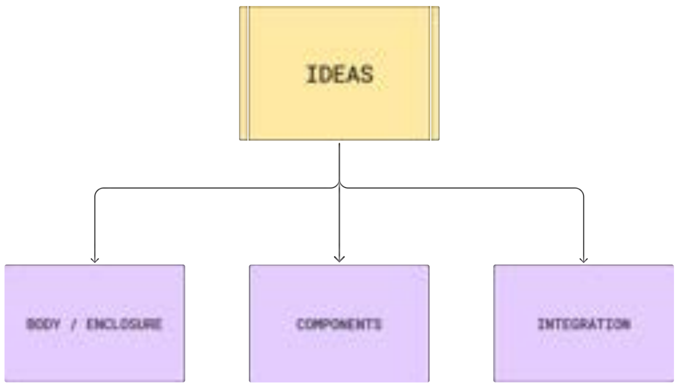

Figure 4.65 The highest level of themes

Theme of Body

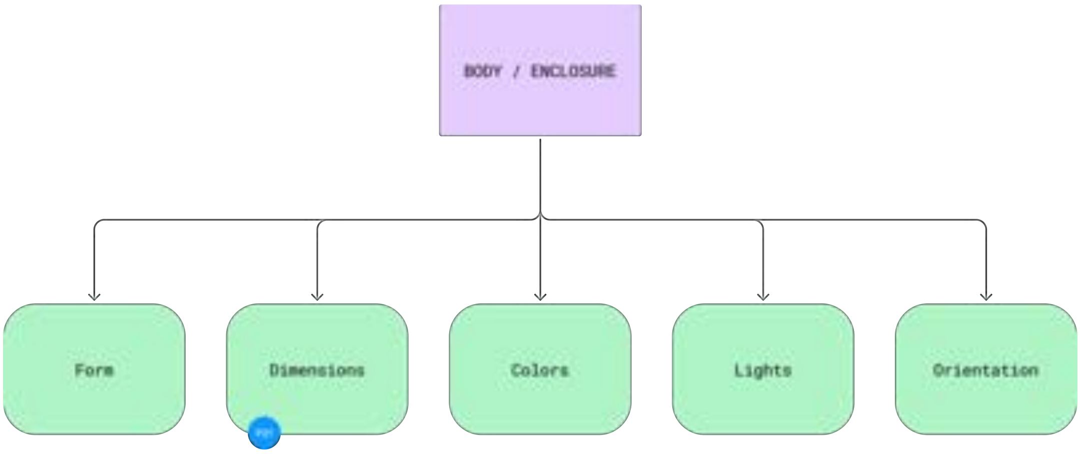

Figure 4.66 Branches of the category of body

The category of form is divided into two sub-categories: rigid and flexible.

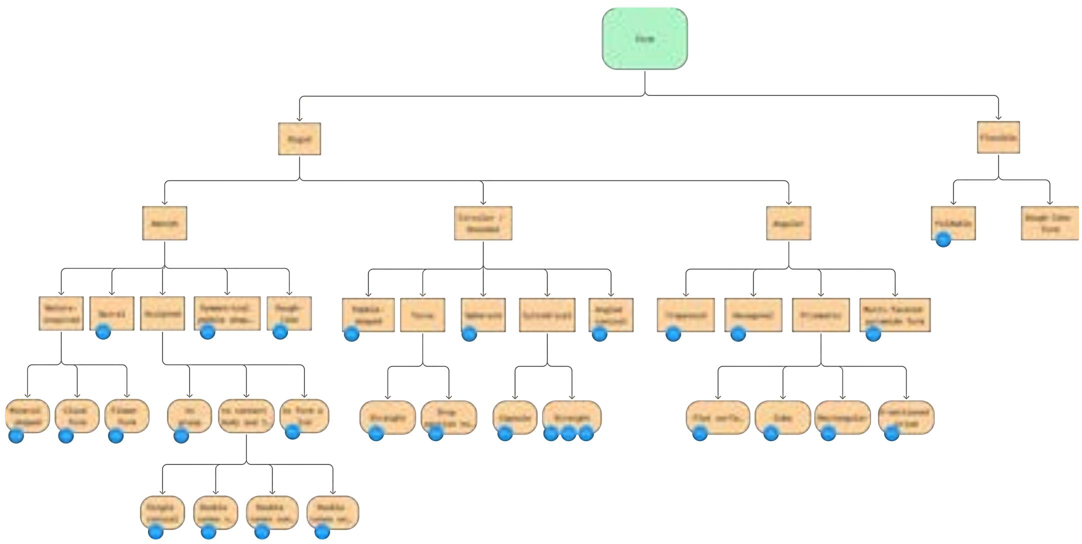

Figure 4.67 Branches of the category of form

Rigid forms are amorphous, circular/rounded, or angular. Amorph ones are nature-inspired, spiral, sculpted, symmetrical pebble shape, or dough-like. Nature-inspired solutions include a mineral-shaped form, a cloud form, or a flower form. Sculpted ones are to grasp, form a lid, and connectthe body and top. The latter ones have a single conical shape, double cones connecting from a small surface, double cones connecting from a long surface, or double cones on top of each other.

Circular/rounded forms are pebble-shaped, torus-shaped, spheroid, cylindrical, or angled conical. Torus-shaped forms are either straight or drop-sectioned. Cylindrical ones are either capsule-shaped or straight-shaped. Angular ones are trapezoid, hexagonal, prismatic, multi-faceted pyramid form. Prismatic ones are formed with flat surfaces with wavy sides, cube shapes, rectangular shapes or D-sectioned surfaces.

Flexible forms are either foldable or dough-like

Figure 4.68 Sketch examples for different form solutions. From left to right: Nature-inspired flower form, foldable, capsule form, and thorus-shaped.

The category of dimensions does not have any leaves and contains one idea belonging to one participant.

The category of colors is divided into two sub-categories: nature-inspired graphical patterns and two color options.

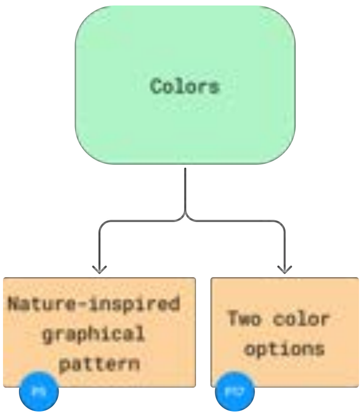

Figure 4.69 Branches of the category of colors

The category of lights is divided into three sub-categories based on the placement of lighting on the speakers: from all edges and round shapes, at the front, and from inner edges, triangular shape.

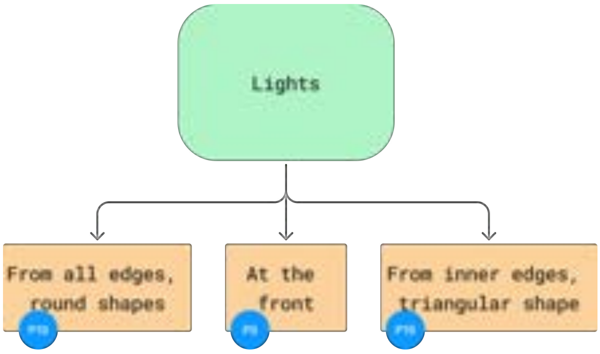

Figure 4.70 Branches of the category of lights

The category of orientation is divided into six sub-categories: self-standing, vertical orientation, hangability, wearability, and rocking on the surface.

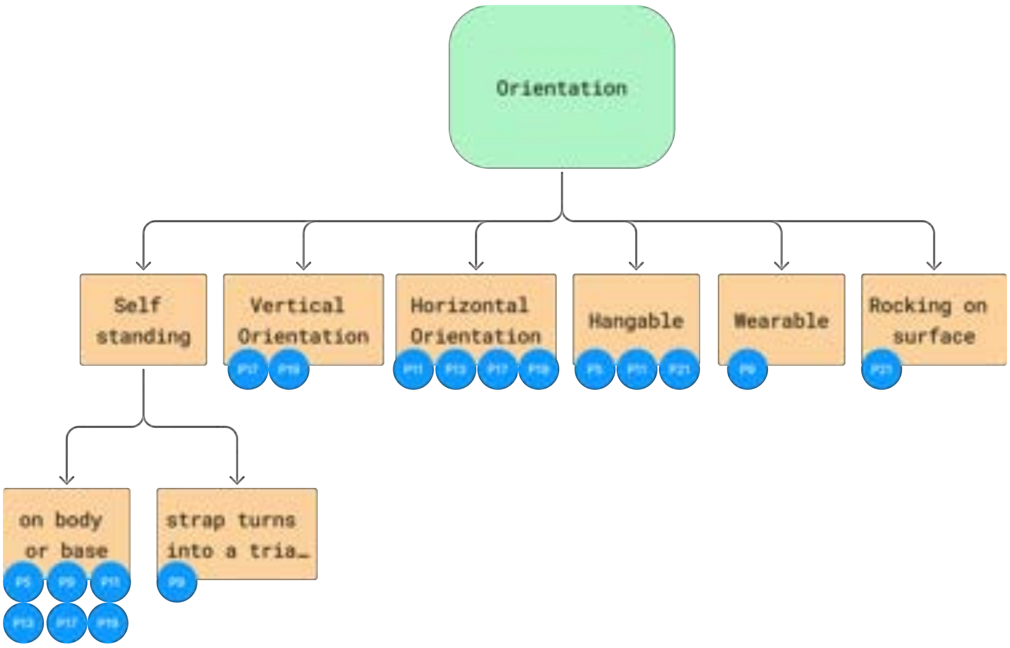

Figure 4.71 Branches of the category of orientation

Self-standing orientations offer two different solution clouds, which are either on the body or base or the strap turns into a triangle base.

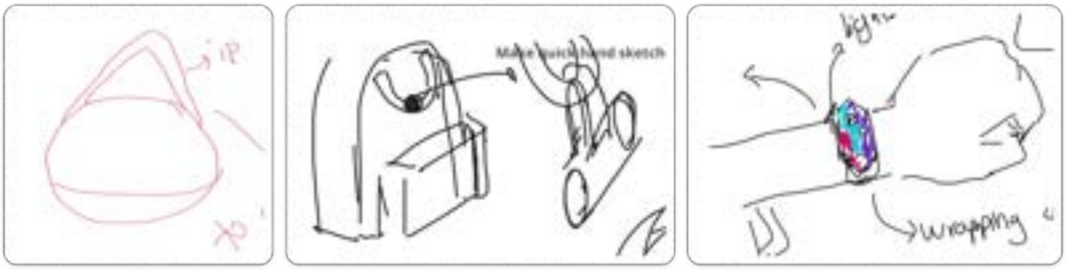

Figure 4.72 Sketch examples for different orientation solutions. Left: Hangable. Middle: Hangable. Right: Wearable.

Theme of Components

The theme of components contains six different categories: charging port, sound output, buttons, feedback lights, display with a flip feature, and handle.

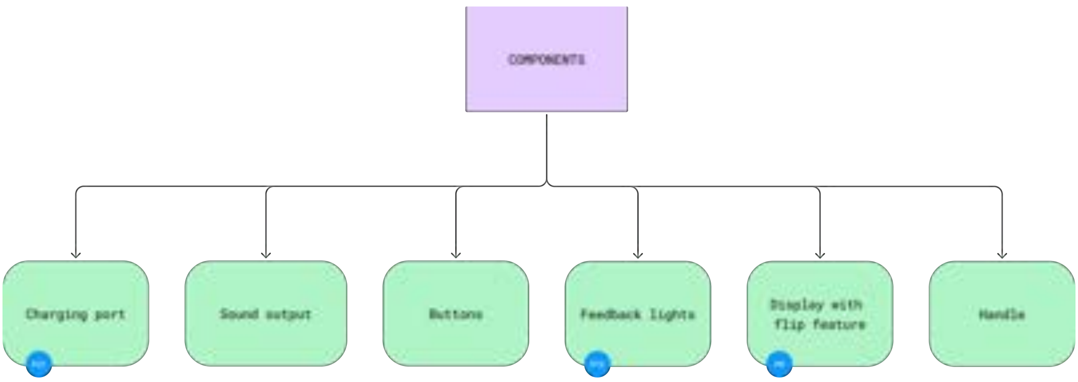

Figure 4.73 Branches of the category of components

The category of charging port does not contain sub-categories because only one student suggests the charging port component within the solution cloud.

The category of sound output contains three sub-categories: sound output at the front face, at three faces with a cylindrical shape and horizontal slits pattern, and at all faces with a triangular shape with a scribble pattern.

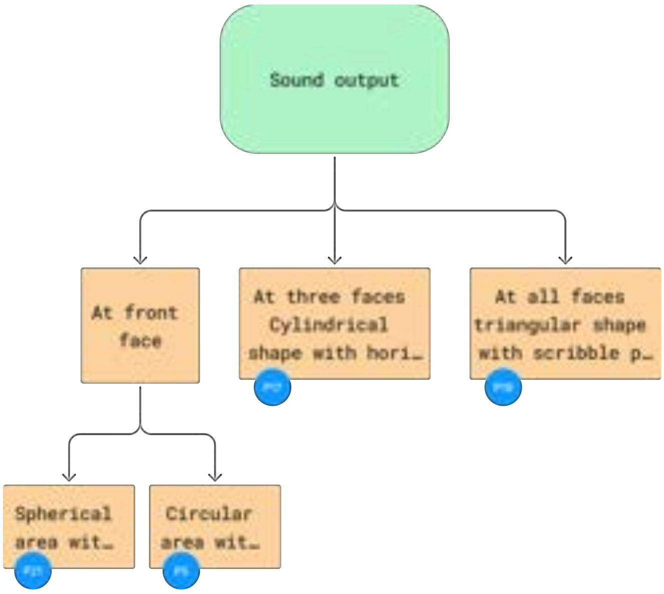

Figure 4.74 Branches of the category of sound output

Solutions for sound output at the front face are either covering a spherical area with a dotted pattern or a circular area with a hole pattern.

The category of buttons is divided into three sub-categories: form, position, and function.

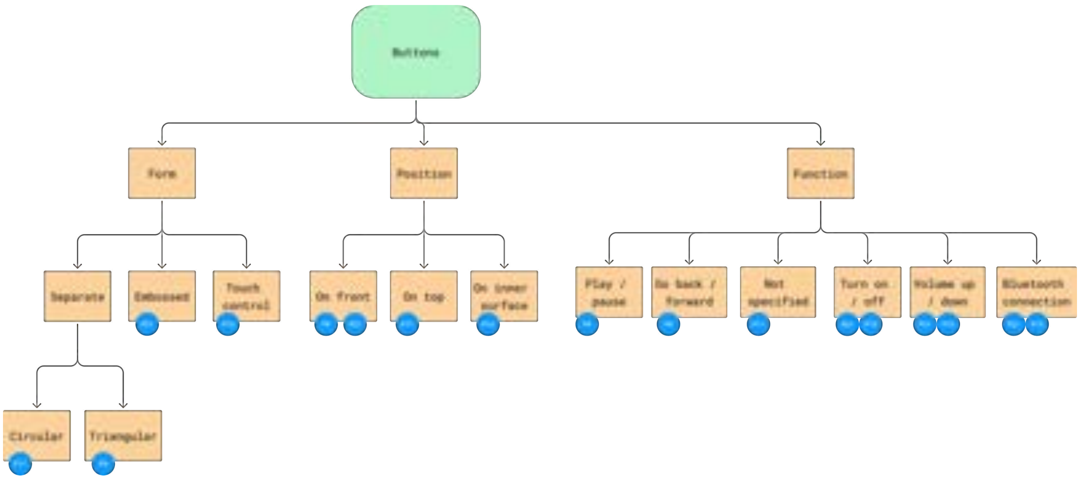

Figure 4.75 Branches of the category of buttons

Form solutions for buttons offer separate forms, embossed forms or a touch control. The separate forms are either circularly shaped or triangularly shaped.

Suggestions for the position of buttons include positioning it on front, on top, or on the inner surface.

Functions of buttons are either for play/pause, go back/forward, turn on/off, volume up/down, Bluetooth connection, or not specified.

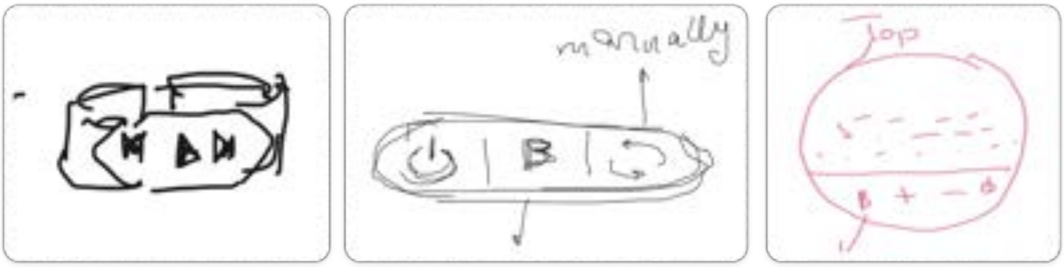

Figure 4.76 Sketch examples for different button solutions. Left: Separate buttons for play/pause and going back and forward. Middle: Touch control with turn on/off, Bluetooth connection and not specified. Right: Embossed buttons for Bluetooth, volume up and down, and turning on and off are placed on the front.

For the category of feedback lights, one student has a suggestion, therefore, the category has no sub-categories.

For the category of display with the flip feature, one student offers a display that can flip according to the placement of the speaker. There are no sub-categories for this category.

The category of handle is divided into two sub-categories: rigid and flexible. Rigid handles include U-shaped clips, magnets, or mounted ones. U-shaped clips are either made of a removable metal or fixed. Mounted ones have either an edgy shape or a curvy shape.

Flexible handles are straps, ropes, loops, or an elastic cord. Straps are either detachable or fixed. Those that are fixed either have a single strap to insert it on a belt or a double fabric strap to hang on the backpack handle, with a stopper detail. Elastic cords are either used to insert it on a belt or to wrap it around the wrist.

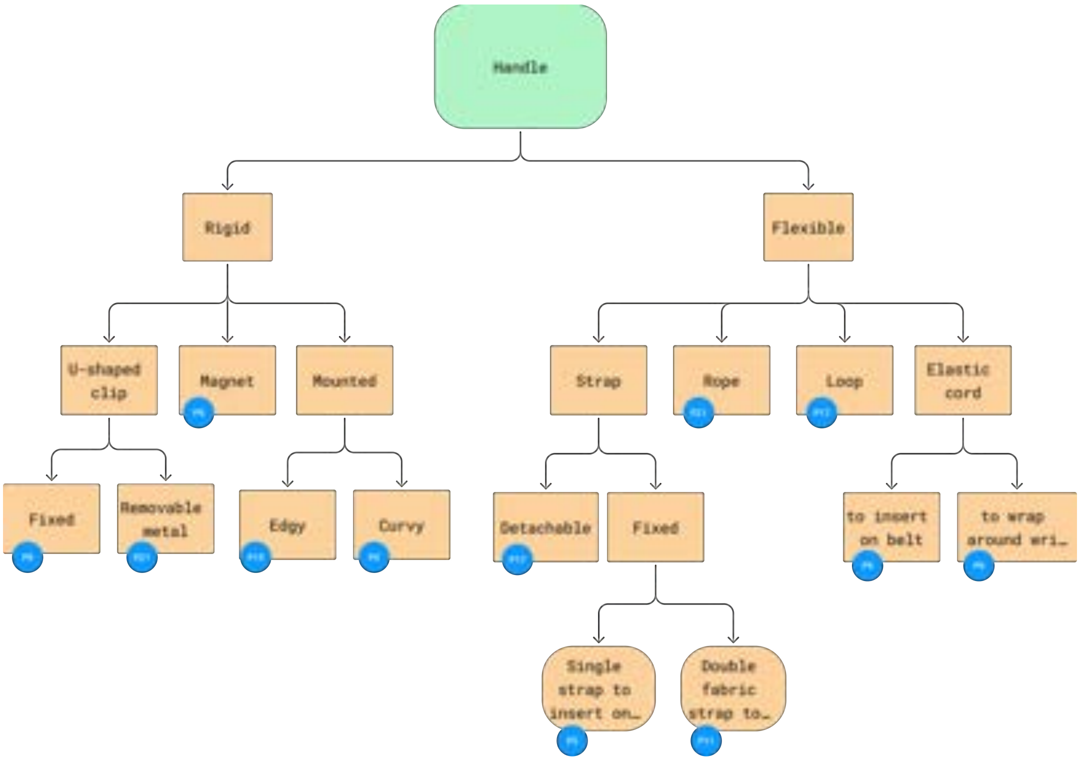

Figure 4.77 Branches of the category of handle

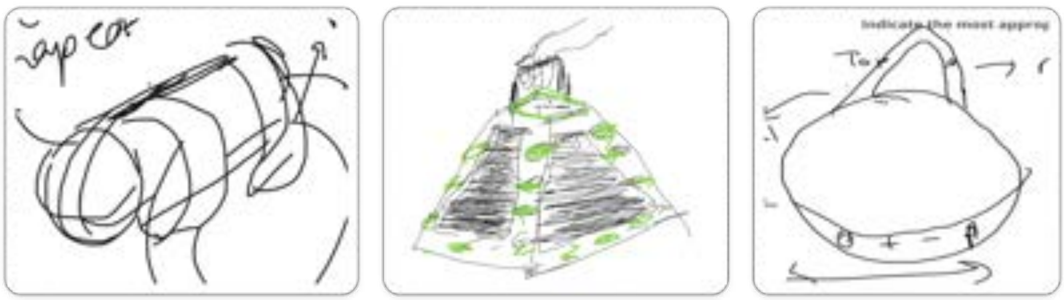

Figure 4.78 Sketch examples for different handle ideas. Left: Double-fabric strap to hang on the backpack handle. Right: U-shaped fixed clip.

Theme of Integration

The theme of integration is divided into three categories: pairing with other speakers without contact, modular components, and mobile apps. All of these categories have one solution that belongs to one participant.

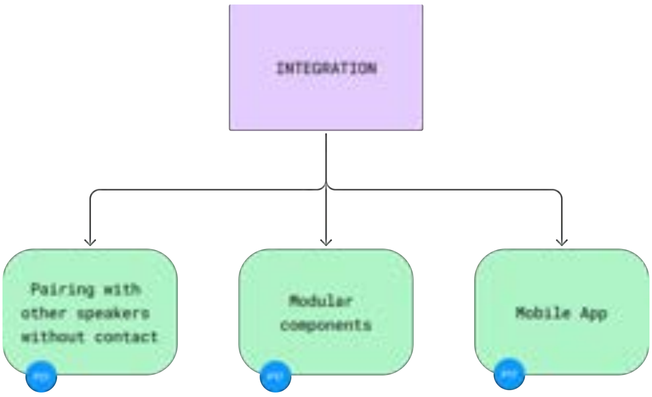

Figure 4.79 Branches of the category of integration

4.2.3 Calculation of the Scores

After each tree and participant label were transferred delicately into the coding space, the novelty and variety scores were calculated in this medium. The verification was made by comparing scores. The quantity scores were calculated manually during the codification sessions initially but then revisited after the codification sessions were completed and reported. Some of the numbers were corrected. The sketches evaluated by using three of the four metrics of ideation effectiveness, which are novelty, variety, and quantity. In the end, each participant received a score for these three metrics for both incubation and control conditions. The expectation was to see an overall rise in all three metrics for participants in the incubation condition compared with the control condition.

Tables 4.2 and 4.3 show the variety, novelty, and quantity scores in two groups categorized based on the design tasks given to the participants during incubation and control conditions, respectively. Table 4.2 includes participants who are given the Blu*etooth speaker* design problem in incubation and the *water bottle* problem in control conditions and Table 4.3 includes participants who are given these problems in the opposite order in incubation and control conditions. While the green rows show an increase in values in the second condition, the blue rows show a decrease, and the grey rows show no difference.

The graphs reveal that in the Bluetooth speaker incubation group, 6 participants exhibited an increase in *variety* scores under the control condition, while 3 showed a decrease. Conversely, in the water bottle incubation group, 3 participants demonstrated an increase in variety scores, whereas 5 participants showed a decrease. Additionally, in Table 4.2, all participants experienced a decrease in novelty under the control condition, whereas, in Table 4.3, only one out of eight participants showed a decrease in novelty. In terms of quantity scores, in the Bluetooth speaker incubation group, seven participants showed a decrease, one participant showed an increase, and one participant's score remained unchanged. In contrast, all participants in the second group demonstrated an increase in quantity scores.

Table 4.2 Variety, novelty, and quantity scores of participants belonging to the group which are given the blueetooth speaker problem in incubation and water bottle problem in control conditions.

	VARIETY			**NOVELTY**			**QUANTITY**	
	bluetooth speaker	*water bottle*		*bluetooth speaker*	*water bottle*		*bluetooth speaker*	*water bottle*
	incubation	control		incubation	control		incubation	control
S01	2.335	3.277	**S01**	9.773	9.596	**S01**	11	11
S03	3.558	3.956	**S03**	9.829	9.693	**S03**	15	11
S04	1.668	2.801	**S04**	9.766	9.555	**S04**	8	8
S06	2.979	3.497	**S06**	9.807	9.632	**S06**	16	11
S08	1.668	3.277	**S08**	9.731	9.639	**S08**	8	10
S10	4.051	2.377	**S10**	9.819	9.685	**S10**	15	10
S12	2.740	2.547	**S12**	9.830	9.632	**S12**	13	9
S14	3.336	2.122	**S14**	9.766	9.545	**S14**	9	6
S16	3.177	3.786	**S16**	9.797	9.599	**S16**	13	10
mean	2.835	3.071	**mean**	9.791	9.620	**mean**	12	9.556

Table 4.3 Variety, novelty, and quantity scores of participants belonging to the incubation water bottle group

	VARIETY			NOVELTY			QUANTITY	
	water bottle	*bluetooth speaker*		*water bottle*	*bluetooth speaker*		*water bottle*	*bluetooth speaker*
	incubation	control		incubation	control		incubation	control
S02	3.512	2.398	**S02**	9.765	9.809	**S02**	8	11
S05	3.302	3.654	**S05**	9.750	9.857	**S05**	12	13
S07	2.859	2.576	**S07**	9.673	9.785	**S07**	6	11
S09	2.870	2.264	**S09**	9.779	9.785	**S09**	9	10
S11	1.809	0.374	**S11**	9.779	9.869	**S11**	6	7
S13	2.649	2.790	**S13**	9.743	9.785	**S13**	6	9
S15	0.642	2.228	**S15**	9.816	9.785	**S15**	4	8
S17	3.571	3.521	**S17**	9.820	9.846	**S17**	7	9
mean	2.652	2.475	**mean**	9.766	9.815	**mean**	7.25	9.75

The data does not meet the assumptions of parametric tests. Therefore, a non-parametric test, Kruskal-Wallis, was conducted to examine whether novelty, variety, and quantity scores differed across the participants considering the interaction of experimental conditions and design tasks: Incubation + Bluetooth Speaker, Control + Water Bottle, Incubation + Water Bottle, and Control + Bluetooth Speaker. Results showed statistically significant differences between the control and incubation conditions for novelty score, $H(3) = 21.8$, $p = 0.0001$, and quantity score, $H(3) = 10.37$, $p = 0.015$. There was no significant difference between the control and incubation conditions for the variety score ($p = 0.640$) or for the average of scores (novelty+variety) ($p = 0.745$). To understand which combination of experimental condition and design task lead to the significance difference between the control and incubation conditions in novelty and quantity scores separately, post hoc tests (multiple comparisons) were performed. The results for each metric are reported in the sections below.

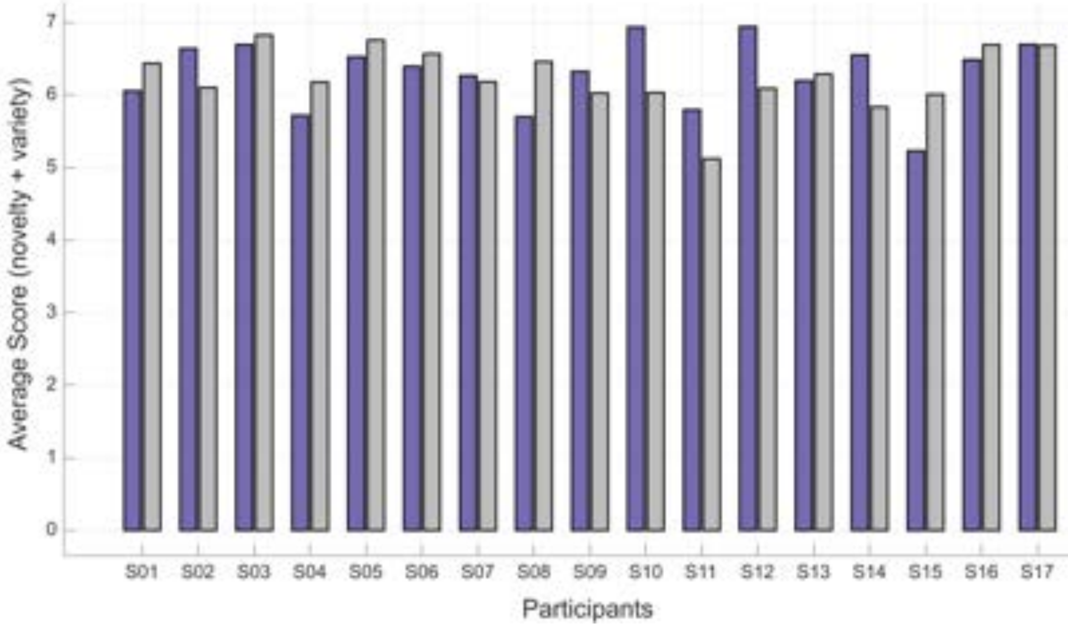

Figure 4.80 The average performance (calculated as the summation of novelty and variety scores) of participants during the incubation and control conditions separatively in purple and grey, respectively.

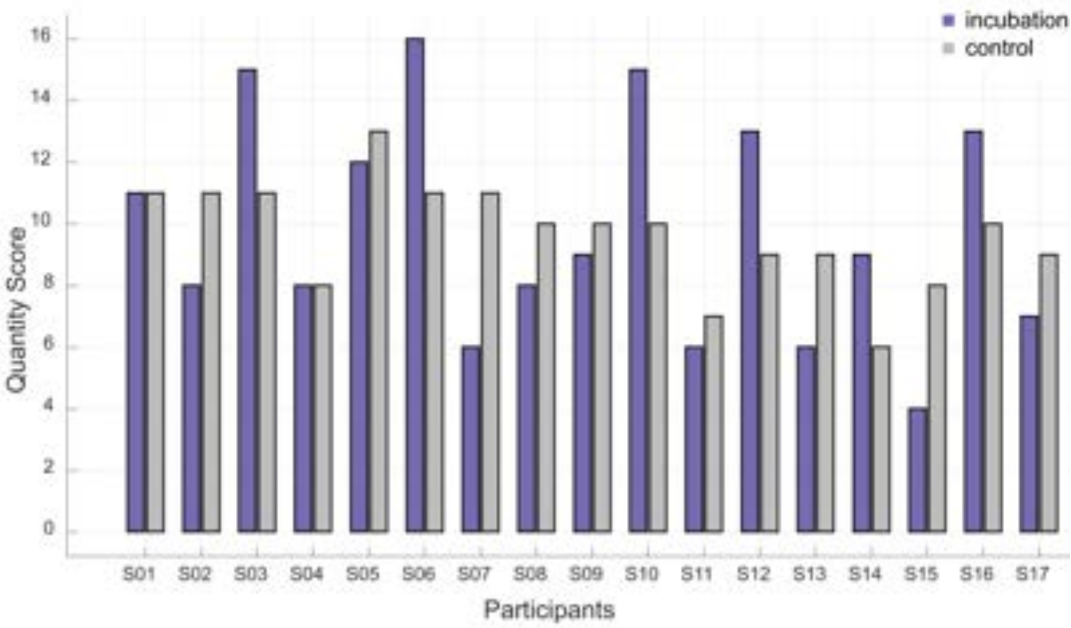

Figure 4.81 The performance in terms of quantity scores during the incubation and control conditions, in purple and grey, respectively.

4.2.3.1 Novelty Scores

The novelty scores are calculated based on Shah's (2003) formula. The score of each node that a student offers a solution is calculated with this formula: N = (T-S) * 10 / T. In this formula, whereas T is the total number of ideas in the tree, S is the total number of ideas for the function in a leaf. After this calculation is done for each leaf, each value is multiplied by the number of ideas the student has in that leaf, and these values are added together and divided by the total number of ideas of the student (number of leaves in this study). Since the participant codes were placed once if they fulfilled the function instead of placing the repeating ideas under each leaf, the number of a leaf at the lowest level for a participant is always 1. Therefore, the multiplication is discarded.

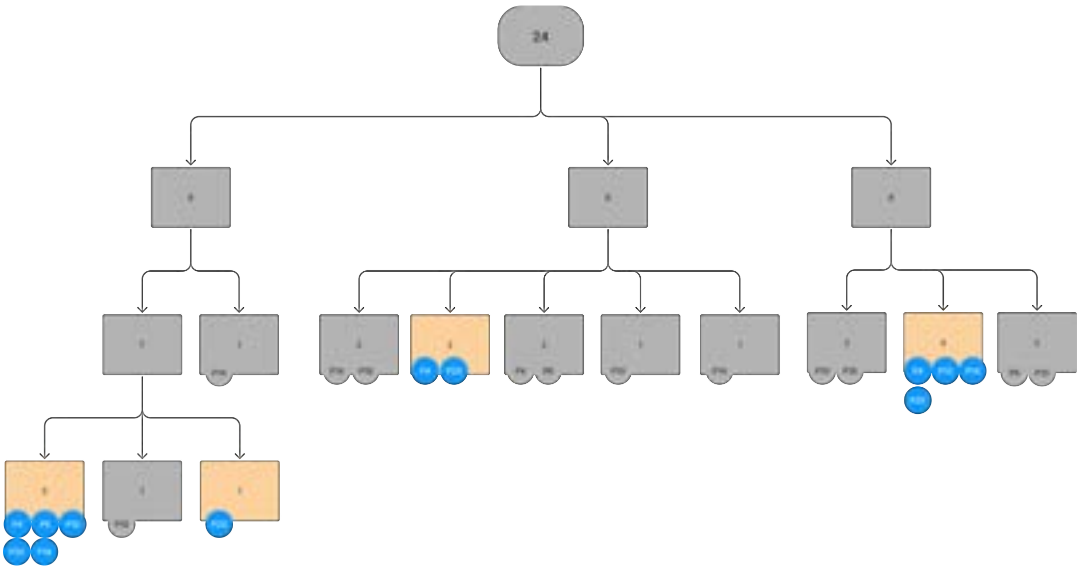

Figure 4.82 A branch from the total tree highlighting leaves belonging to S16.

Figure 4.84 shows a branch from the water bottle control condition. Each leaf has labels belonging to participants who offer a solution for that function. The yellow leaves are included in the formula as the number of ideas for the function (S) with suggestions from different students.

Assuming this branch is the total tree, the T value would be 24. Starting from the left, S values are 5, 1, 2, and 4 in order. Thus, following the formula (N = (T-S) *

10 / T), the novelty scores belonging to each leaf are 7,916 ((24-5)*10/24), 9,583 ((24-1)*10/24), 9,166 ((24-2)*10/24) and 8,333 ((24-4)*10/24). Then, the novelty score of S16 can be calculated by summing these values and dividing it into the total number of ideas of the student: (7,916+9,583 +9,166+8,333)/4 = 8,7495.

Regarding the analysis, first, we wanted to see how the novelty scores for each participant in two experimental conditions vary. The novelty scores of each participant according to the experimental conditions are presented in the following table. While 7 out of 17 participants showed an increase in scores from the incubation to the control condition, while 10 out of 17 participants showed a decrease.

Furthermore, Table 4.4 show the grouped novelty scores based on the design tasks as participants are given different design tasks in incubation and control conditions. While the participants highlighted with blue indicate a decrease in the control condition (all of the incubation + bluetooth speaker & control + water bottle group as well as one participant from the incubation + water bottle & control Bluetooth speaker group), green indicates an increase in the control condition (all but one of incubation+water bottle & control+Bluetooth speaker group).

For the Bluetooth speaker task, participants in the incubation condition scored slightly higher (mean = 9.791) compared to the control condition (mean = 9.620), with individual scores ranging from 9.731 to 9.830 for incubation and 9.545 to 9.693 for control. On the other hand, for the water bottle task, participants in the control condition scored slightly higher (mean = 9.815) compared to the incubation condition (mean = 9.766), with individual scores ranging from 9.785 to 9.869 for control and 9.673 to 9.820 for incubation.

Table 4.4 Summary of the novelty scores

	incubation	control
S01	9.773	9.596
S02	9.765	9.809
S03	9.829	9.693
S04	9.766	9.555
S05	9.750	9.857
S06	9.807	9.632
S07	9.673	9.785
S08	9.731	9.639
S09	9.779	9.785
S10	9.819	9.685
S11	9.779	9.869
S12	9.830	9.632
S13	9.743	9.785
S14	9.766	9.545
S15	9.816	9.785
S16	9.797	9.599
S17	9.820	9.846
mean	9.779	9.712

Table 4.5 Summary of the novelty scores according to design tasks

	bluetooth speaker	*water bottle*
	incubation	**control**
S01	9.773	9.596
S03	9.829	9.693
S04	9.766	9.555
S06	9.807	9.632
S08	9.731	9.639
S10	9.819	9.685
S12	9.830	9.632
S14	9.766	9.545
S16	9.797	9.599
mean	9.791	9.620

	water bottle	*bluetooth speaker*
	incubation	**control**
S02	9.765	9.809
S05	9.750	9.857
S07	9.673	9.785
S09	9.779	9.785
S11	9.779	9.869
S13	9.743	9.785
S15	9.816	9.785
S17	9.820	9.846
mean	9.766	9.815

Figure 4.85 and 4.86 illustrate these results. In Figure 4.85, the distribution of novelty scores for different experimental conditions, incubation, and control, is shown, pooled across the design problem given in each. We performed the Kruskal-Wallis test to compare these conditions and found that there is a significant difference between the control and incubation conditions for the novelty scores (p = 000.1).

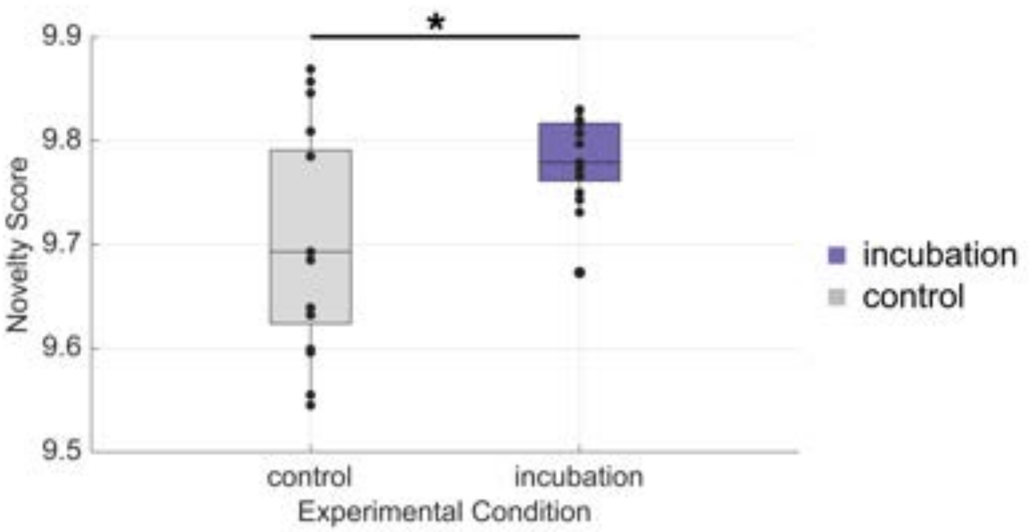

Figure 4.83 Boxplot of novelty scores in the control and incubation conditions. Each dot represents a participant.

To further explore whether this difference between the conditions is affected by the design problem given to the participants, we separated the scores based on the design problem given in each condition to further explore whether the design problem affects the novelty scores in each experimental condition. The results can be seen in Figure 4.86 below.

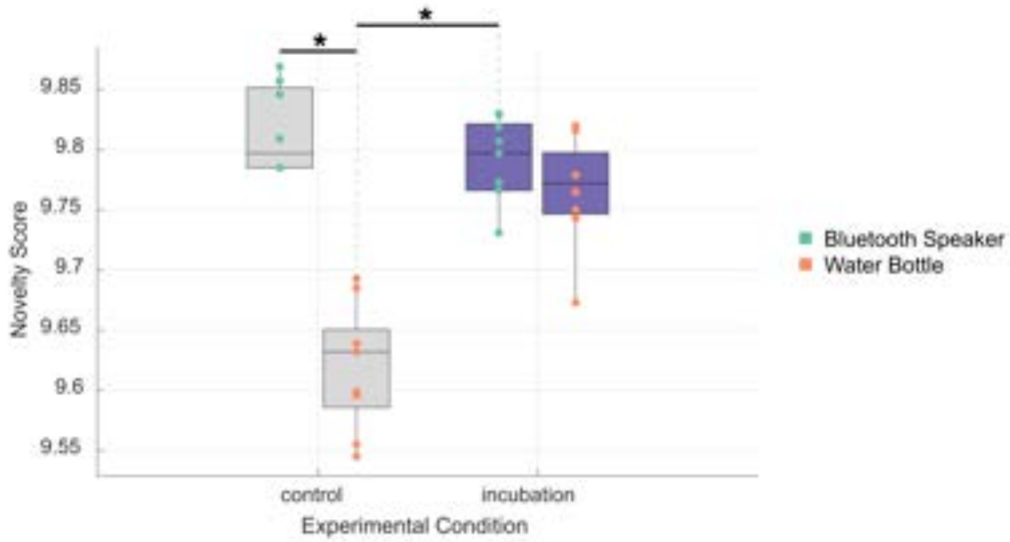

Figure 4.84 Distribution of novelty scores in conditions and among design tasks. Each dot represents a participant and the color of the dots represents the design task they were given.

It can be seen from the figure that there is an increase in the novelty scores of participants who generated solutions for the Bluetooth speaker task in the incubation condition and the water bottle task in the control condition. However, there is a slight decrease in the novelty scores of participants who generated solutions for the water bottle task in the incubation condition and the Bluetooth speaker task in the control condition. It should be noted that the participants who created solutions for the Bluetooth speaker task in the control condition and for the water bottle task in the incubation condition are the same individuals. Similarly, participants who created solutions for the water bottle task in the control condition are the same individuals in the Bluetooth speaker-incubation condition. Post hoc comparisons using multiple comparisons were conducted to identify specific pairwise differences in novelty scores between the experimental condition-design task pairs.

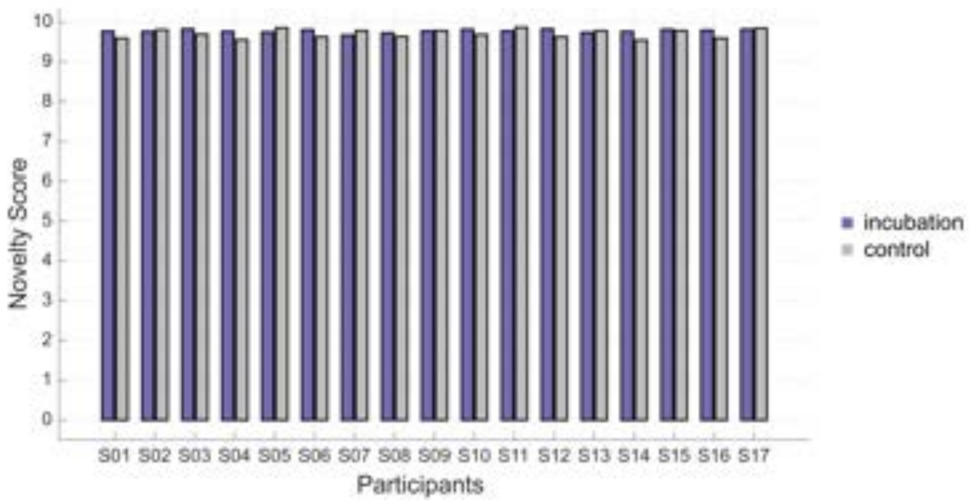

Figure 4.85 Bar graph showing the difference in novelty scores between control and incubation conditions

Post hoc comparisons using multiple comparisons were conducted to identify specific pairwise differences in novelty scores between the experimental condition-design problem pairs. The scores for the group who solved the Bluetooth speaker task in the incubation condition (Mean = 218.89, SE = 3.32) were significantly higher as compared to their scores in the control condition in which they solved the water bottle task (Mean = 5.22, SE = 3.32), with a mean difference of 166.67 (p = 0.0494) (Figure 4.87)., which shows that novelty scores for the incubation Bluetooth speaker group benefited from the incubation period.

Additionally, the control Bluetooth speaker group (Mean = 263.75, SE = 3.52) scored significantly higher than the control water bottle group, with a mean difference of 211.53 (p = 0.0001). No other comparisons were statistically significant for novelty scores.

4.2.3.2 Variety Scores

The variety scores were calculated following the method mentioned in Chapter 3.5.2. The formula by Shah (2003) for calculating the variety score of each student offers to multiply the number of nodes at each hierarchical level by the level value that corresponds to it. Next, each sum is added and divided by the overall number of ideas belonging to the participant to determine the score. On the other hand, Nelson (2009) suggests subtracting one from the number of nodes at a hierarchical level and the overall number of ideas to preserve and reflect the variety in lower levels. However, both calculations make the comparison between participants challenging because they do not take the variety in the total tree into account.

The formula of Bayırlı (2018) suggests following Nelson's (2009) approach to reflect the variety in lower levels when calculating the level scores. Furthermore, he proposes to multiply the sum by ten and divide it by the total tree's variety score. Since his proposal provides a medium for comparison and normalization, it is adopted to calculate variety scores in this thesis. The formula is: $V_{participant} = ((N-1)*W) *10/ V_{total}$. In this formula, N indicates the nodes belonging to a participant at one hierarchical level, and W is the level weight value attained for this level. The number of nodes at each hierarchical level is multiplied by the level value at each level to determine the score. Each sum is then added and multiplied by 10. Following this, the value is divided into the total variety score of the tree. The logic of multiplying 10 is to keep the scores between 0 and 10. The reason for dividing the score into the variety score of the tree is to enable a comparison between participants in reference to the total tree.

The variety score of the tree is calculated by multiplying the number of nodes (belonging to all participants) minus one at each hierarchical level by the corresponding level weight, and each sum is then added.

Assuming that this branch is a total tree and the variety score of S16 is intended to be calculated. The dark yellows represent the leaves, and the bright yellows represent the nodes within the branch that goes up to the root.

Starting with the calculation of the total tree's variety score, the levels' values are multiplied by the number of nodes in that level regardless of the participant. The values are summed after this calculation is made for each level. Thus, the total variety of this tree is (5*3)+(3*10)+(1*3)=48.

Then, S16's score can be calculated as follows: (5*(3-1))+(3*(3-1))+(1*(2-1))*10/48 = 3,541.

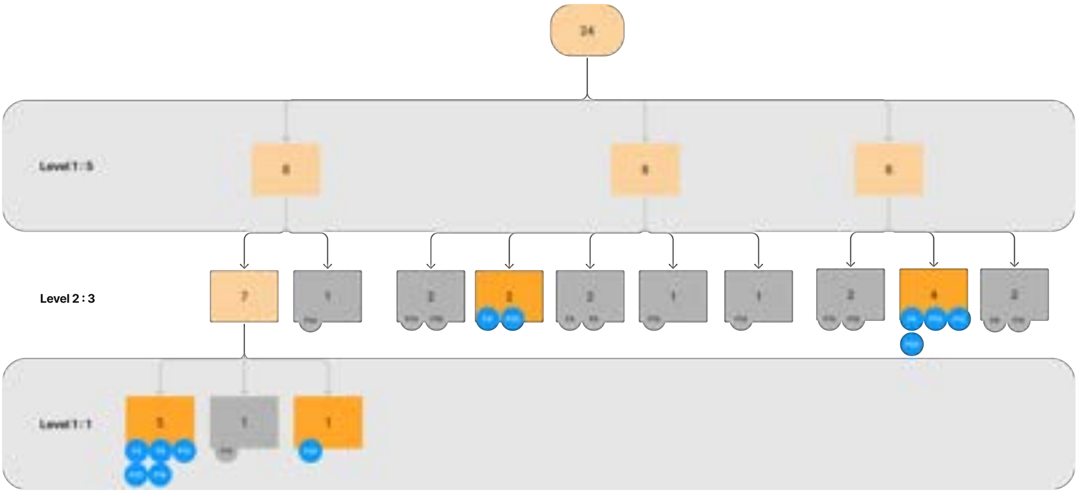

Figure 4.86 Branch of a tree highlighting leaves and nodes belonging to S16

Regarding the analysis, as in the case for the novelty scores, we first wanted to observe the distribution and range of the individual variety scores for each participant and for each experimental condition (Table 4.6). As it is explained in the section 3.5.2.3.2, the variety scores are calculated based on the level weight and the node numbers according to each level. There are six hierarchical levels for the control water bottle group, and the level weights were determined as 20, 15, 10, 5, 3, and 1 in descending order. There are seven levels for the incubation water bottle group, and the level weights are determined as 25, 20, 15, 10, 5, 3, and 1 in descending order. It is vice versa for the Bluetooth speaker groups. The participants highlighted with blue show a decrease in the control condition compared to the incubation condition and it the opposite is observed fot the participants marked with green.

The following table represents the variety of values of each participant's incubation and control condition. The following graphs show the variety scores grouped based on design tasks.

Table 4.6 Summary of the variety scores

	incubation	control
S01	2.335	3.277
S02	3.512	2.398
S03	3.558	3.956
S04	1.668	2.801
S05	3.302	3.654
S06	2.979	3.497
S07	2.859	2.576
S08	1.668	3.277
S09	2.870	2.264
S10	4.051	2.377
S11	1.809	0.374
S12	2.740	2.547
S13	2.649	2.790
S14	3.336	2.122
S15	0.642	2.228
S16	3.177	3.786
S17	3.571	3.521
mean	2.749	2.791

Next, we wanted to see how or whether this trend between control and incubation conditions are affected by the type of design problem the participants are given at each condition. To that end, we separated the participants into two groups based on the experimental condition – design problem pairs. The table below (Table 4.7) show the variety scores based on this grouping.

Table 4.7 Summary of the variety scores according to the design tasks

	bluetooth speaker	*water bottle*
	incubation	**control**
S01	2.335	3.277
S03	3.558	3.956
S04	1.668	2.801
S06	2.979	3.497
S08	1.668	3.277
S10	4.051	2.377
S12	2.740	2.547
S14	3.336	2.122
S16	3.177	3.786
mean	2.835	3.071

	water bottle	*bluetooth speaker*
	incubation	**control**
S02	3.512	2.398
S05	3.302	3.654
S07	2.859	2.576
S09	2.870	2.264
S11	1.809	0.374
S13	2.649	2.790
S15	0.642	2.228
S17	3.571	3.521
mean	2.652	2.475

In terms of the Bluetooth speaker task, participants in the incubation condition scored an average of 2.652, in the incubation condition, which is slightly higher than the control condition's mean of 2.475 when they are presented with the same design task. When the participants are given the blueetooth speaker task, their individual variety scores in the incubation condition ranged between 0.642 and 3.571, while their variety scores in the control condition ranged between 0.374 and 3.654. Conversely, for the water bottle task, participants performed better under the control condition, with a mean score of 3.071, compared to the mean score of 2.835 in the incubation condition.

To better illustrate the distribution and range of above-mentioned scores, we have plotted them across two experimental conditions as seen in Figure 4.89. The Kruskal-Wallis test did not reveal any significance between the control and incubation conditions for the variety scores (p = 0.6408).

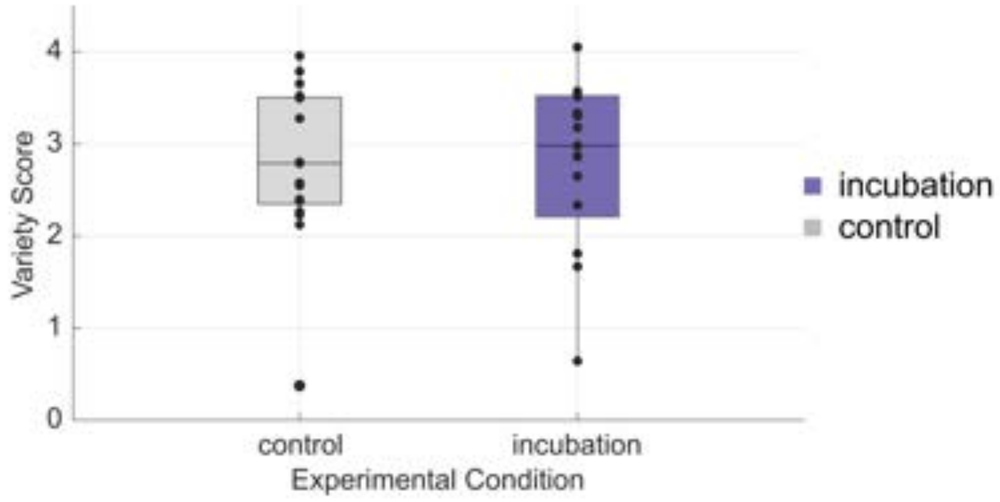

Figure 4.87 Boxplot of variety scores in the control and incubation conditions. Each dot represents a participant.

The figure above shows the pooled results across design tasks for control and incubation conditions, respectively. We wanted to further assess whether the variety scores are affected by the design problem given to the participants. The results can be seen in Figure 4.90. It can be seen that while the variety scores in the incubation condition are lower than the control condition when the participants are presented with the water bottle task, it is vice versa for when they are given the Bluetooth speaker task.

It is important to note that the participants who worked on the Bluetooth speaker task under the control condition also worked on the water bottle task under the incubation condition. Likewise, those who worked on the water bottle task in the control condition were the same individuals who tackled the Bluetooth speaker task under the incubation condition.

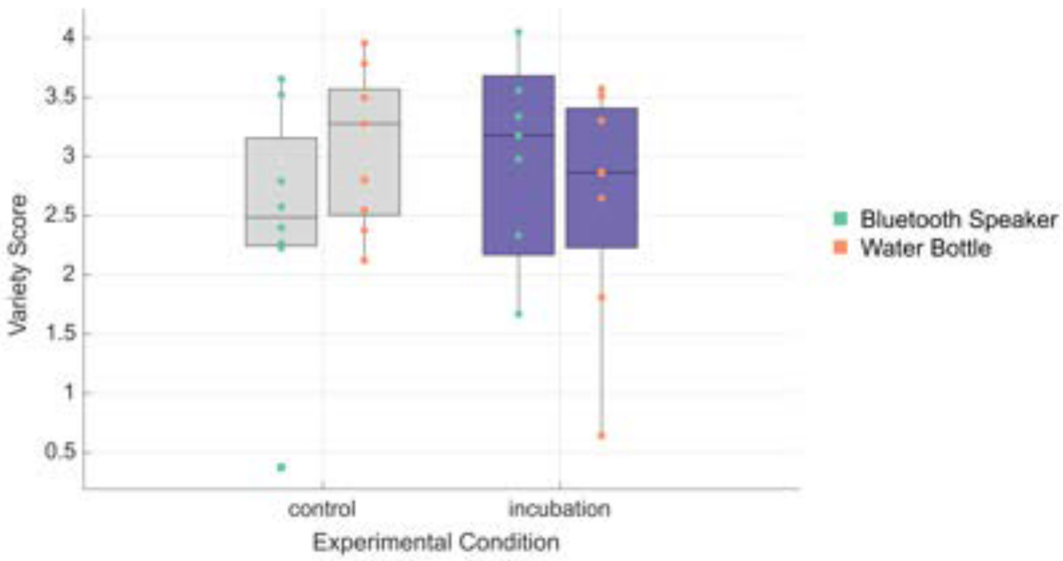

Figure 4.88 Boxplot of variety scores separated by design tasks in the control (grey) and incubation (purple) conditions. Each dot represents a participant and color of the dots represents the design task they were given.

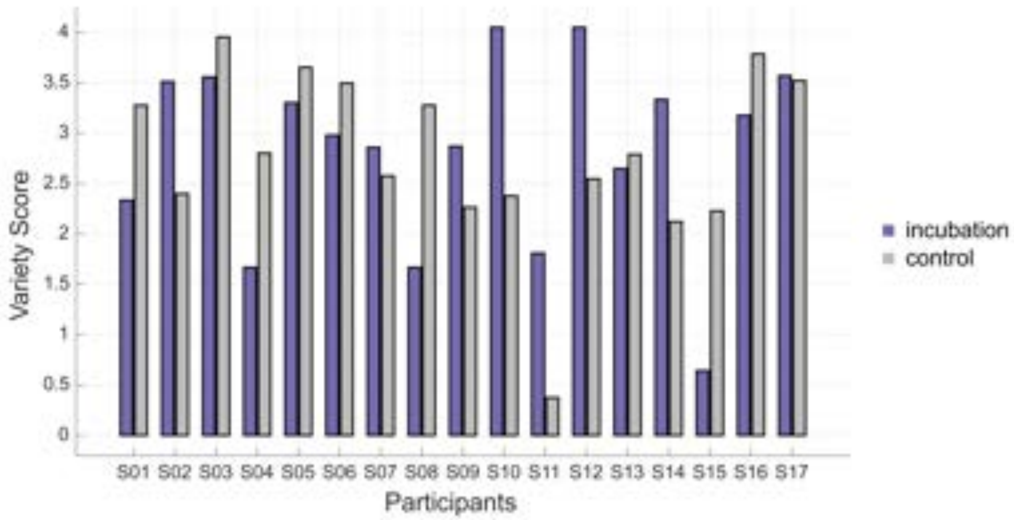

Figure 4.89 Bar graph showing the difference in variety scores between control and incubation conditions

Although a slight increase is observed in the group who solved the water bottle task in the control condition and the Bluetooth speaker task in the incubation condition, and a slight decrease is observed in the group who solved the water bottle task in the incubation condition and the Bluetooth speaker task in the control condition, since Kruskal Wallis test did not reveal any significant differences($H(3)=1.68$, $p=0.6408$), no post hoc tests are conducted.

4.2.3.3 Quantity Scores

The quantity scores were calculated manually during the codification sessions by counting the different ideas generated by each student. They were later reviewed and finalized after the sessions had concluded.

For the analysis, first we looked at the individual scores and how it varied across participants, for incubation and control conditions separately (Table 4.8). The participants highlighted with blue show a decrease in quantity scores in the control condition compared to the incubation condition and it is the opposite for participants marked in green.

Table 4.8 Summary of the quantity scores

	incubation	**control**
S01	11	11
S02	8	11
S03	15	11
S04	8	8
S05	12	13
S06	16	11
S07	6	11
S08	8	10
S09	9	10
S10	15	10
S11	6	7
S12	13	9
S13	6	9
S14	9	6
S15	4	8
S16	13	10
S17	7	9
mean	9.76	9.65

It can be seen from the table that the number of ideas offered for the water bottle task by students on average is lower for the incubation condition than the control condition. On the contrary, the number of ideas for the Bluetooth speaker task is higher in the incubation condition than in the control condition. Next, we wanted to see whether this difference is affected by the specific combination of experimental condition and the design task and looked at the distribution of quantity scores for each, dividing the participants into two groups based on the specific combination they are offered (Table 4.9).

Table 4.9 Summary of the quantity scores according to the design tasks

	water bottle	**bluetooth speaker**
	incubation	control
S02	8	11
S05	12	13
S07	6	11
S09	9	10
S11	6	7
S13	6	9
S15	4	8
S17	7	9
mean	7.25	9.75

	bluetooth speaker	**water bottle**
	incubation	control
S01	11	11
S03	15	11
S04	8	8
S06	16	11
S08	8	10
S10	15	10
S12	13	9
S14	9	6
S16	13	10
mean	12	9.556

When the participants are given the water bottle task, they scored an average of 7.25 in the incubation and 9.75 in the control conditions, respectively, indicating higher performance in terms of the number of ideas generated. Individual scores range from 4 to 12 in incubation and 7 to 13 in control. On the other hand, for the Bluetooth speaker task, incubation condition scores have a higher mean (12) compared to the control condition's mean (9.556), with individual scores ranging from 8 to 16 in incubation and 6 to 11 in control. It should be noted that incubation conditions are always followed by the control condition and participants are presented with different design tasks in each. To better illustrate the distribution, the differences and the potential order effect (of experimental condition-design task combinations), we plotted the scores across the conditions and the design tasks as in Figure 4.92.

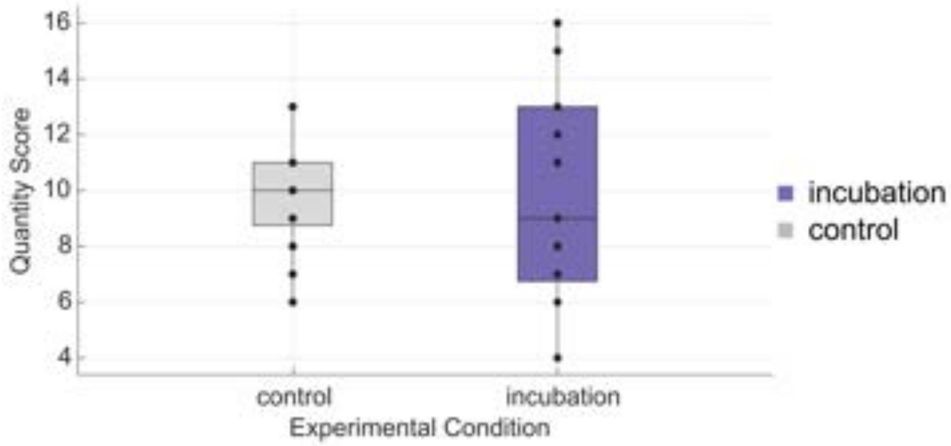

Figure 4.90 Boxplot of quantity scores during control and incubation conditions

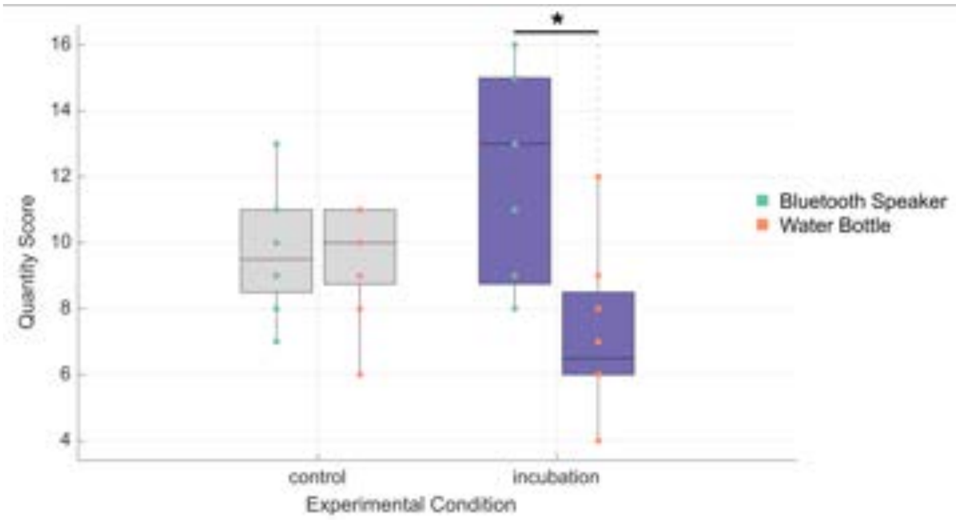

Figure 4.91 Boxplot of quantity scores for design tasks and conditions

The quantity scores, i.e. the number of solutions created in the incubation condition are higher for participants who generated solutions for the Bluetooth speaker task as compared to those who generated solutions for the water bottle task. Multiple comparisons test revealed that the scores in the incubation-Bluetooth speaker group (Mean = 242.78, SE = 3.29) are significantly higher than the incubation-water bottle group (Mean = 8.88, SE = 3.49), with a mean difference of 154.03 ($p=0.0073$) (Figure 4.93).

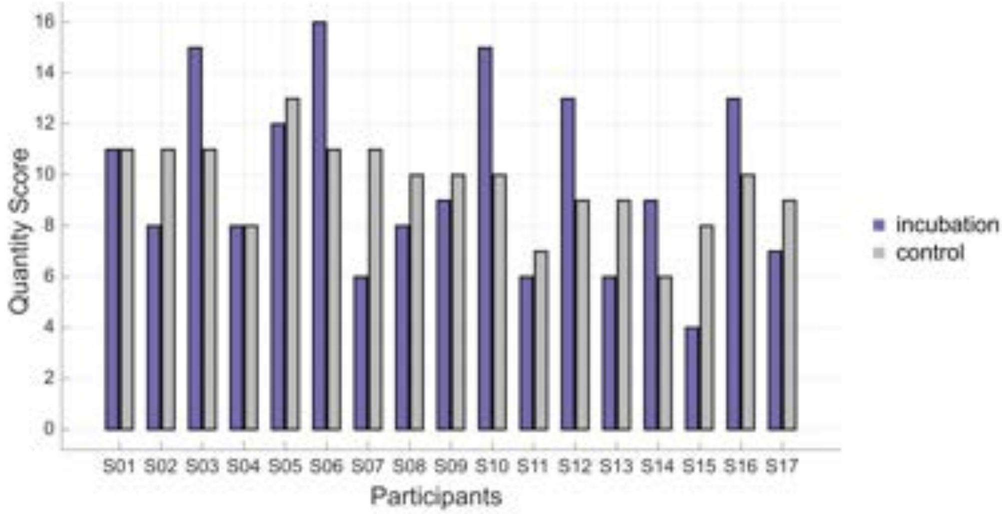

Figure 4.92 Bar graph showing the difference in quantity scores between the control and incubation conditions

4.3 Oscillatory Data

EEG data contain oscillations that are seen over a broad frequency range. The measurement of electrical potential differences between pairs of electrodes forms its basis (Baillet et al., 2011). The range of oscillations is separated into discrete frequency bands such as delta (0.1 to < 4 Hz), theta (4 to < 8 Hz), alpha (8 to < 13 Hz), beta (13 to 30 Hz), and gamma (> 30 to 80 Hz) (Pernet et al., 2018). The changes in the brain's electrical activity are measured by microvolt units (Cohen, 2014).

This study utilized a BrainAmp Amplifier to obtain 32-channel EEG data with the sampling frequency of 1KHz. Impedance levels were aimed to be kept under 10kΩ (kiloohms), with several exceptions. The electrodes were positioned in accordance with the standard international 10-20 system and installed in an elastic cap. Ground electrodes were positioned on the earlobes, and reference electrodes were positioned at the mastoids. EOGs were obtained using two electrodes that were positioned below the right eye for vertical movements and to the right of the eye for horizontal movements. The recordings were held in a Faraday cage in order to minimize electrostatic interferences. All steps of analysis were taken in MATLAB, using the Fieldtrip Toolbox that was developed by Oostenveld and colleagues (2011).

The signals were bandpass filtered with cut-off frequencies of 1 and 40Hz and demeaned. Due to the noise at 50Hz caused by the wireless connection between the drawing tablet and pen, a bandstop filter with cut-off frequencies of 48 and 52Hz was applied.

Since EEG is sensitive to electrical current that is not only generated by the brain but also by devices and power lines, it is important to recognize artifacts and clean the data before further processing. Signals captured by the EEG that are not produced by the brain are called artifacts. The artifacts in the dataset were eliminated mostly based on visual inspection (Figure 4.95).

Several exceptions in the dataset required independent component analysis (ICA), which separates data into subcomponents (Figure 4.96). Data belonging to 4 participants underwent this process due to the noise that could not be rejected visually or might have caused a major loss with manual inspection.

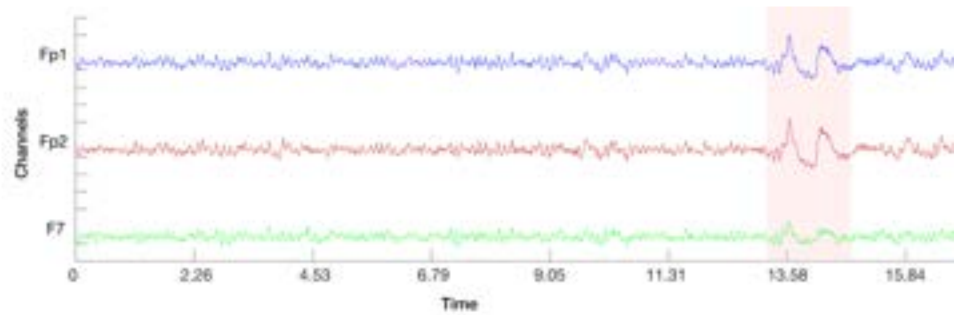

Figure 4.93 Three channels from EEG data under artifact inspection procedure. The red rectangle shows the segment that is indicated as noise and to be removed from the data.

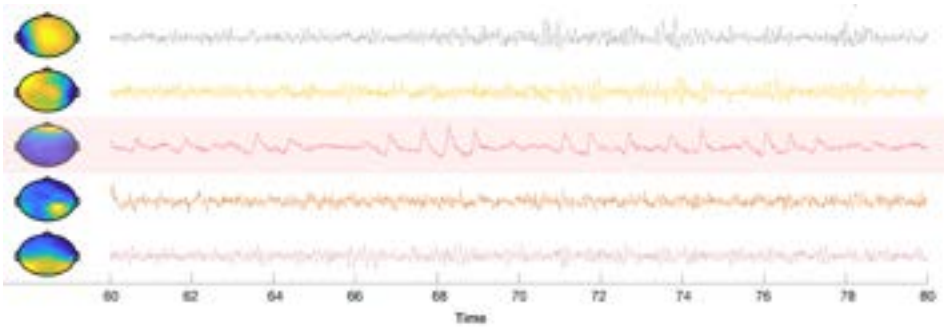

Figure 4.94 Artifact rejection with ICA. The figure shows five components among 30 components of the data in the time axis and in topographical graphs. The component that is highlighted with red triangle was considered to contain eye movement artifacts.

The following graphs show the topographical distribution of alpha power for the subject S02 before and after ICA implementation.

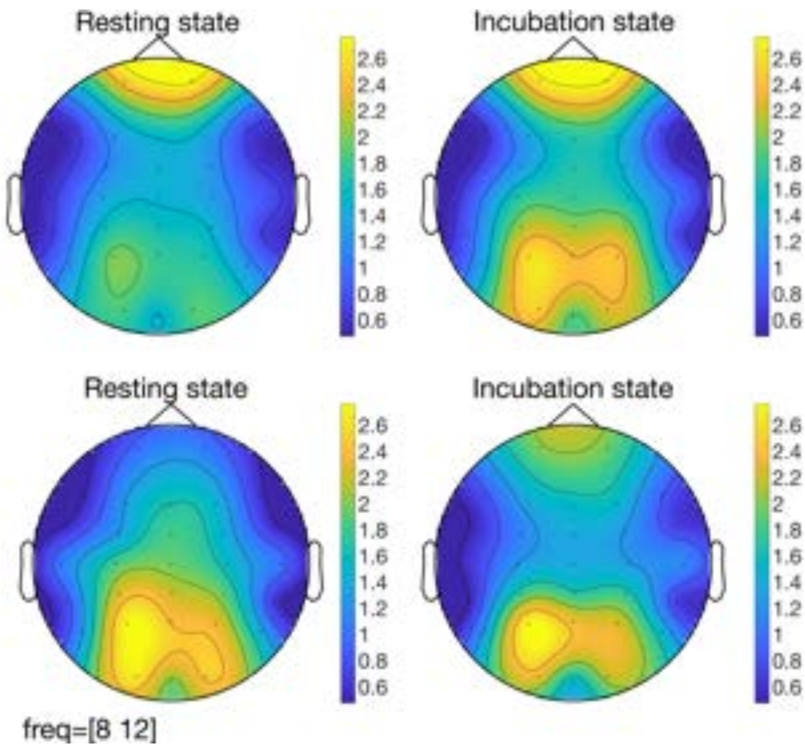

Figure 4.95 The change in the topographical distribution of alpha power for the resting period (left column) and incubation period (right column) for alpha band range (8-12 Hz). The first row shows power spectra for the subject S02 data cleaned with visual inspection. The second row shows power spectra after ICA implementation. The power at the frontal area before ICA implementation shows possible eye artifacts.

EEG data were gathered throughout the design process, covering two design tasks, to reach consistency among experimental conditions. However, the analysis primarily focused on data from the resting and incubation periods of the first condition. Therefore, the data segmentation according to the markers placed on the signals took place at first. The average recording duration for the incubation period was 244 ± 2 seconds, while for the resting period, it was 240 ± 11 seconds.

Then spectral analysis was performed. The following figures show the entire analysis pipeline used in the oscillatory analysis.

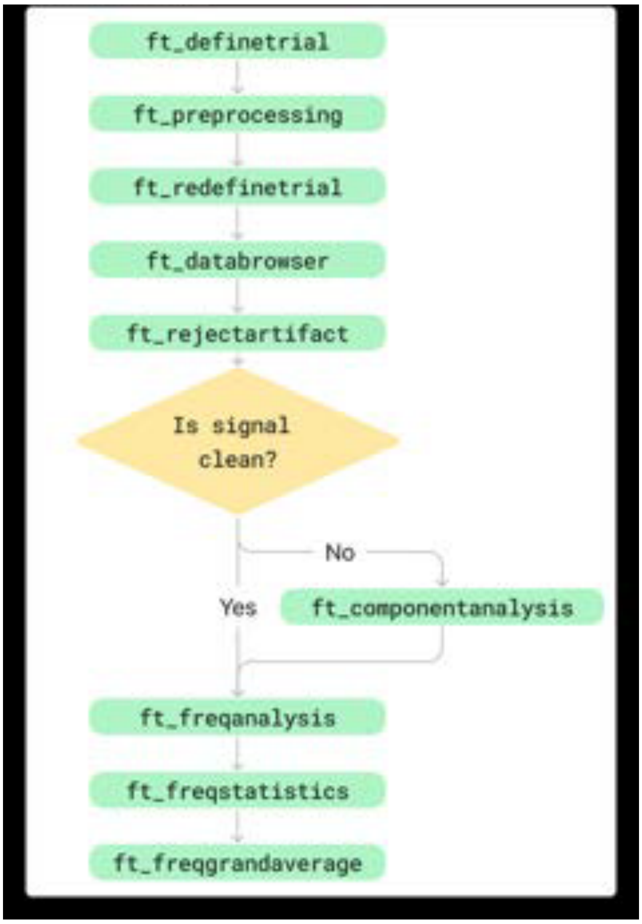

Figure 4.96 Analysis pipeline showing Fieldtrip Toolbox functions employed in each step in preprocessing followed with spectral analysis and cluster-based permutation analysis.

Spectral analysis is used for computing band-specific frequency power. Because it was aimed to see the average power throughout the recording process, and the averaging would eliminate the difference in trial numbers, the length was set to be the highest time points available for each participant. This analysis enabled to see the power changes within1-40Hz interval.

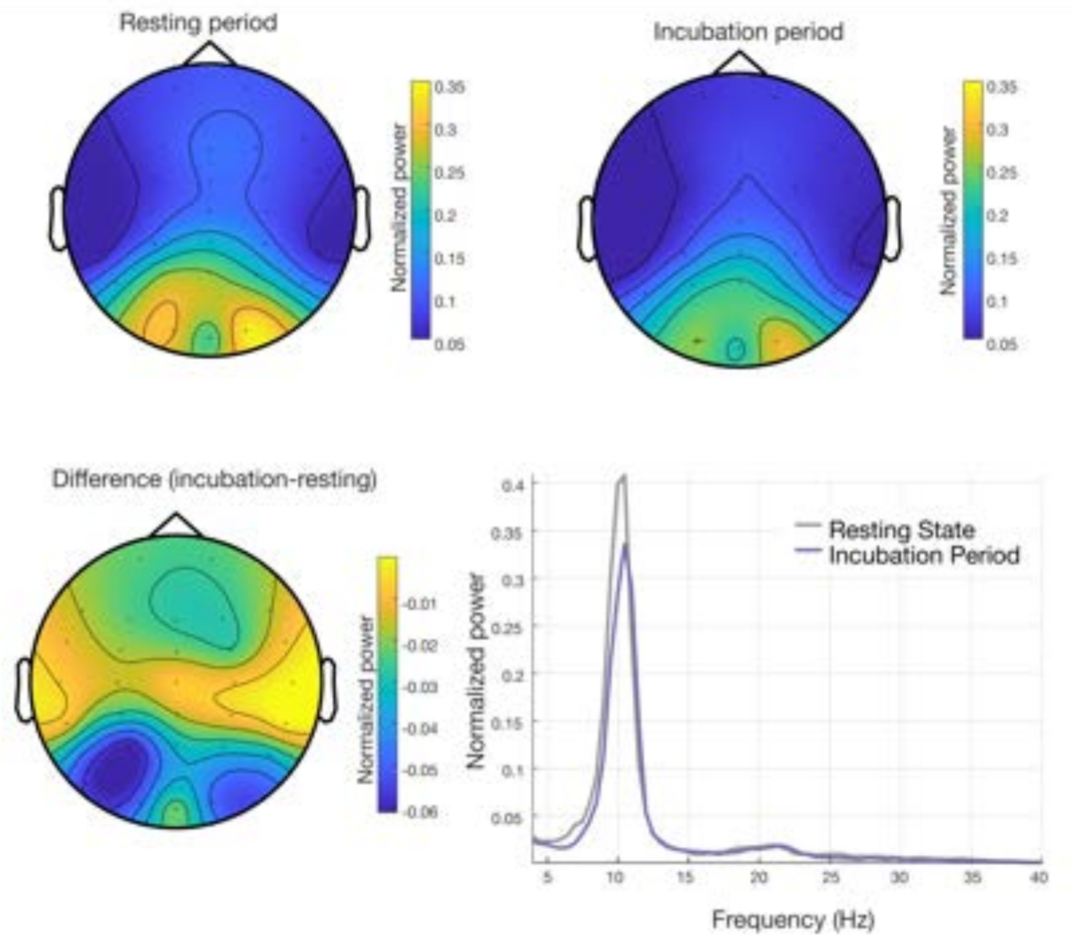

Figure 4.97 Topographical distribution of normalized power for a representative participant (S13) over the alpha band (8-12Hz) for the resting period (top left), and for the incubation period (top right). The difference in power (incubation-resting) over alpha band, is shown at the bottom left. The power spectrum for P4 channel is on the bottom right.

Alpha band activity was anticipated during the recordings, as they were conducted in eyes-closed states. This expectation aligned with the visual inspection in the power spectra. Since closing the eyes enhances alpha activity, reflecting a relaxed and disengaged brain state and a decrease in alpha during eyes closed state reflects a cognitive function, alpha band (8-12Hz) was chosen to proceed with the statistical analysis.

Two participants' data were eliminated from the dataset since no alpha power was observed. One of these participants was intermittently opening their eyes during rest and incubation periods, although they were instructed to close their eyes, which is another reason for eliminating the data of this participant. Eventually, the cluster-based permutation analysis was conducted with 15 participants.

In order to eliminate the effect of individual differences in the analysis, each participant's data was normalized by dividing the power values in incubation and resting conditions by the maximum power value within the resting period in the power dimension of the data. Moreover, for each participant, the peak in the alpha band is taken as the individual alpha frequency (IAF) and the participants' spectral data is shifted accordingly (Haegens et al., 2014). Because the peak frequency within the alpha band varies widely among individuals, adjusting frequency bands to IAF allows for maintaining consistency across participants and prevents the overlapping of different frequency bands (Klimesh, 1999). It is followed by selecting the 4Hz window by extracting power values around the alpha peak within the -2Hz and +2Hz frequency bands. This approach ensured accurate interpretation of the statistical results by accounting for inter-subject variability in alpha peak frequencies. This step was followed by the statistical analysis.

The cluster-based permutation test overcomes the problem of multiple comparisons by identifying groups of connected data points instead of testing each point individually, which keeps error rates under control. Additionally, it is more sensitive because it takes advantage of patterns in the data, such as clusters of neighbor channels, making it easier to detect meaningful differences between conditions (Maris and Oostenveld, 2007). Therefore, this method was chosen to proceed with statistical analysis.

Data visualization was performed at each stage of the oscillatory analysis pipeline to verify artifact detection, preprocessing effectiveness, and the meaningfulness of frequency decomposition. The subject-specific power spectra representations of each participant are documented in Appendix M.

For the statistical analysis, a cluster was considered significant if its Monte Carlo probability surpassed the 0.025 threshold for each tail when compared to the distribution. The test revealed significance (p = 0.0032) for a negative cluster within the high alpha (10-12Hz) band range in the frontal, central, temporal, and parietal regions (Klimesch, 1999) (Figure 4.100).

The following graphs show the grand averages of resting and incubation periods, followed by the difference highlighting negative clusters within 10-12 Hz. The graphs on the bottom show the average spectral power for resting and incubation states with standard errors on the mean values of the significant cluster.

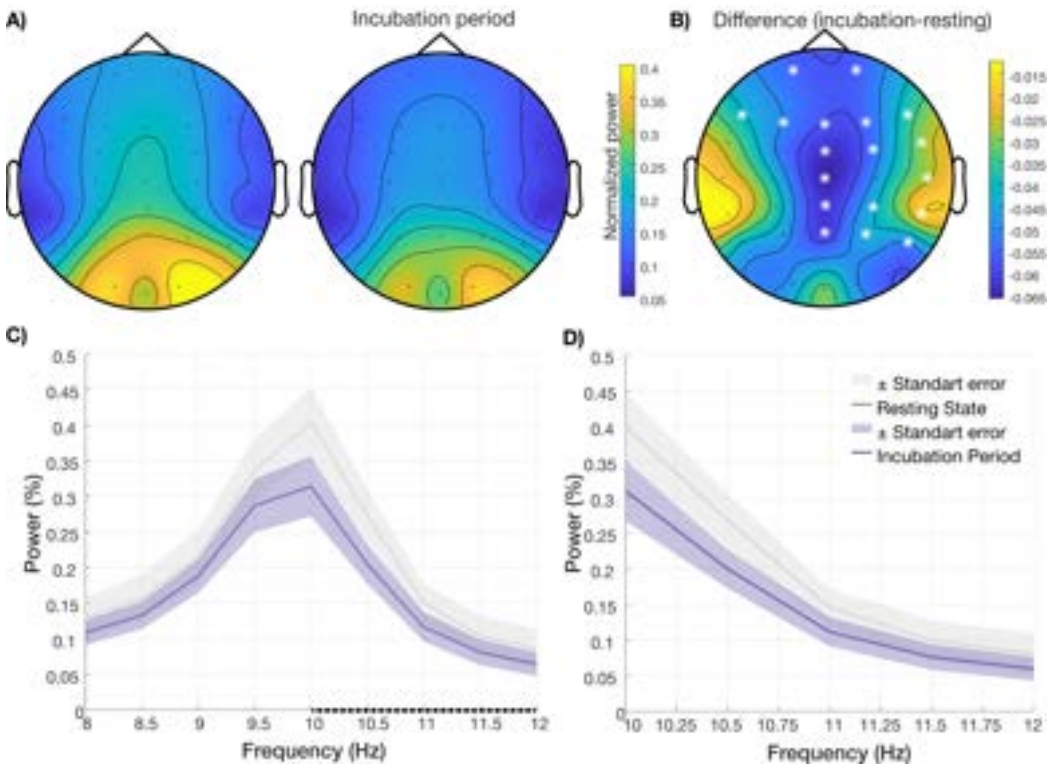

Figure 4.98 A) Grand average of resting and incubation periods within 10-12 Hz intervals. B) The difference between conditions (incubation-resting) showing the

spatial characteristics of the negative cluster on the upper alpha band. C) Variation of alpha power (with standard errors) averaged over frontal, central, and parietal channels for incubation and resting states. D) Variation of upper alpha power (with standard errors) averaged over frontal, central, and parietal channels for incubation and resting states showing where significant difference is revealed (p = 0032).

The following graph shows the significant negative cluster in the alpha range within 1Hz frequency intervals.

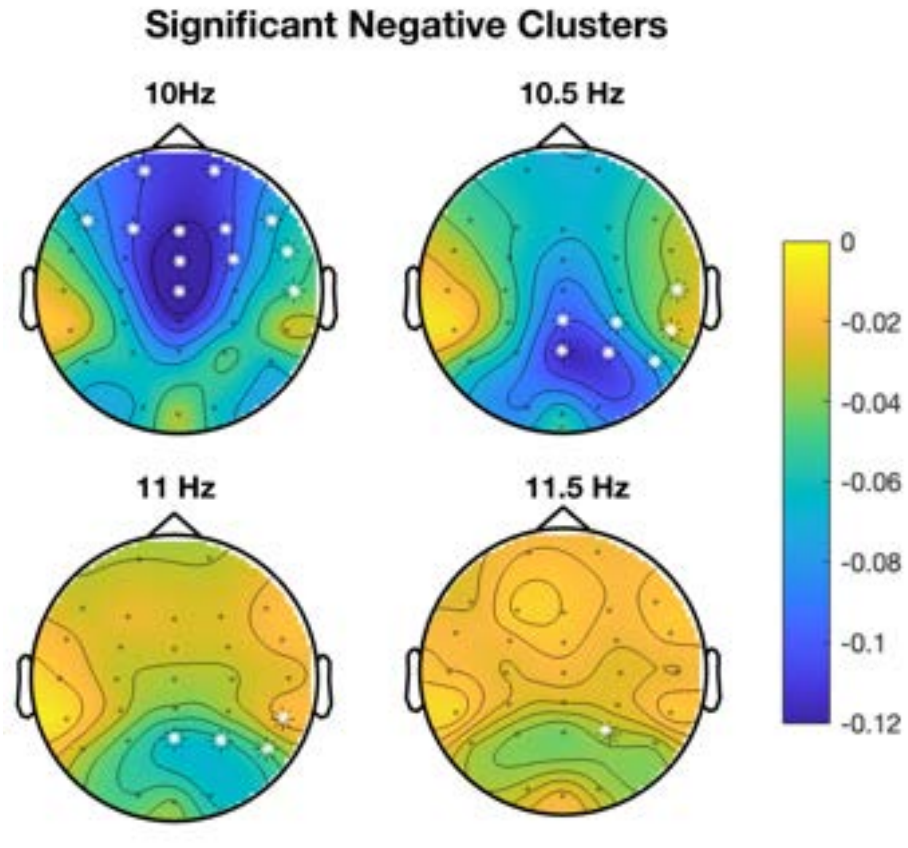

Figure 4.99 Spatial dynamics of the cluster. The asterisk symbols mark the channels in the significant cluster.

The results showed significance on upper alpha (10-12 Hz) with the strongest differences in the 10-11 Hz band, particularly over frontal, central, and parietal regions. Negative power values indicate a reduction in power during the incubation condition as compared to the resting condition.

4.4 Correlational Analysis

The correlational analysis was conducted in MATLAB, integrating findings from self-reports, sketch evaluations, and oscillatory neural activity to uncover relationships between these datasets. The self-report data, initially visualized to observe distributions, were incorporated as predictors in the analysis. Sketch evaluation metrics during the incubation condition, including novelty, variety, and quantity, were paired with oscillatory activity in the significant cluster to explore potential neural underpinnings of creative performance. Oscillatory activity then was correlated with both self-reports and design outputs to determine whether incubation influenced neural dynamics and how these changes related to creative potential and task performance.

The correlational analysis was first conducted on the following couples: (1) upper alpha suppression and creative performance scores, (2) creative potential scores, and upper alpha suppression. While incubation scores are included for sketch evaluations, the relative difference between resting and incubation periods was calculated for the upper alpha data. During this evaluation, two outliers were eliminated from the analysis.

Following testing primary assumptions, the relationship between contributing variables was investigated with different combinations. For example, while the correlation between upper alpha suppression and creative performance did not reveal any significance, it was expected to see a negative relationship between upper alpha suppression and novelty since the novel connections come from semantically distant connections and the observed cognitive activity is related to inhibited semantic network activity. As it was expected, the correlation between upper alpha suppression and novelty revealed an almost significant negative correlation. The significance was coming from the frontal channels, revealing a significant negative correlation between frontal upper alpha suppression and novelty ($p<0.05$) (Figure 4.102).

A significant positive correlation ($p < 0.05$) was found between the creative potential scores and upper alpha suppression in the temporal and parietal regions (Figure 4.103). A comparison of the two self-reports revealed that this significance primarily stems from the intrinsic motivation scores.

Further analysis was conducted to enhance data interpretation. The correlation between creative potential and creative performance scores showed no significant relationship, irrespective of experimental conditions. Additionally, no significant differences were observed in the correlation between design task groups within the incubation condition, during the incubation period.

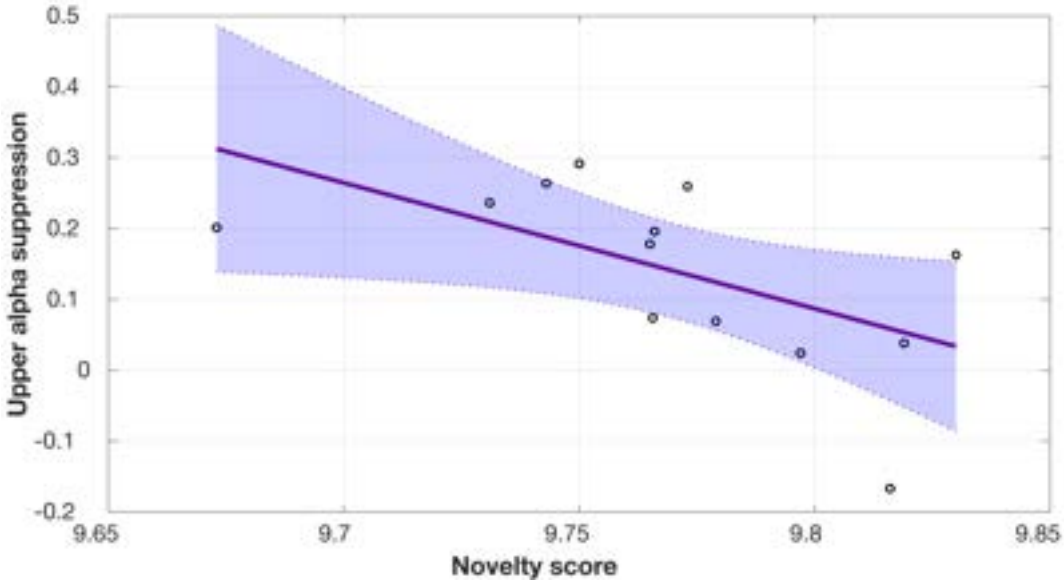

Figure 4.100 A negative correlation between upper alpha suppression in frontal channels and the novelty scores ($r = -0.58$, $p = 0.0382$).

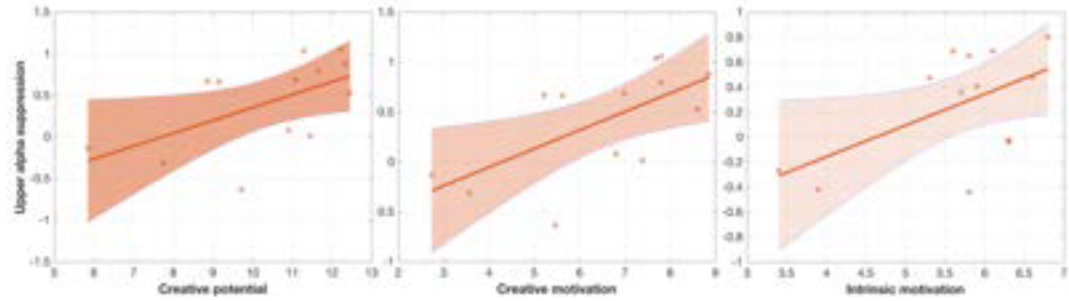

Figure 4.101 Left: Positive correlation between upper alpha suppression in the negative cluster channels and the sum of creative potential scores (r = 0.56, p = 0.444). Middle: Positive correlation between upper alpha suppression in the negative cluster channels and creative motivation (r = 0.64, p = 0.194). Right: Positive correlation between upper alpha suppression in the significant central, parietal, and temporal channels and the intrinsic motvation (r = 0.56, p = 0.0465).

4.5 Discussion

In this chapter, three distinct types of data were reported, each with unique qualities: while the survey data was inherently quantitative, the sketch data was transformed into quantitative measures using two adapted analysis methods, and the signal data was processed to extract relevant features, with the significance of findings reported for sketch and signal analysis. When examined individually, these datasets highlight distinct dimensions of incubation and design creativity. Furthermore, their combination offers a more unique understanding, as the correlations between these datasets allow for more concrete conclusions about the role of incubation in the creative design process.

Significant differences in novelty scores were observed between the two conditions in sketch evaluation. However, this significance was only evident in the incubation-Bluetooth speaker group, while the opposite effect was observed in the incubation-water bottle group. This suggests that the effect cannot be solely attributed to incubation without considering the potential influence of the design task type. In order to understand the causal relationship between design tasks and novelty scores, the participants were separated into two groups based on the design tasks.

No significant results were derived for both groups in their correlations for novelty and alpha suppression, suggesting that the significance comes from the cumulative effect of design tasks. This indicated that the observed novelty differences are unlikely to be driven by the design task alone. Yet, the reduced sample size in subgroups makes it more challenging to draw definitive conclusions from the data.

Turning to sketches, visual differences in the branching patterns of genealogy trees between the two tasks further highlight task-specific characteristics. The Bluetooth speaker's genealogy tree comprises 80 nodes, predominantly organized under technological and system-level components. In contrast, the water bottle's tree includes 51 nodes, primarily representing physical structures, the main body, and limited product-product integrations. For the control conditions, the number of nodes for the Bluetooth speaker is 76, while it is 49 for the water bottle task.

Despite this fact, since further analysis of the correlation between alpha suppression and novelty scores within the two groups (incubation-water bottle and incubation-Bluetooth speaker) revealed no significant relationship, it indicates that the type of problem alone does not fully account for the observed increase in novelty scores but also the effect of incubation.

The EEG results revealed an inverse relationship between alpha suppression in the frontal regions and participants' novelty scores, with higher levels of alpha suppression associated with lower novelty scores. Given that upper alpha suppression is linked to cognitive processes involving the semantic network, and the combinations formed within this network are directly associated with the degree of novelty in solutions, it is unsurprising that this mechanism influences novelty metrics more significantly than other sketch evaluation metrics.

The correlation between the EEG results and survey data highlights a relationship between creative potential and upper alpha suppression in the parietal and temporal regions of the brain. Creative motivation and creative thinking skills were combined as predictors of creative potential, revealing a significant positive correlation between creative potential and alpha suppression in these regions.

Further analysis indicated that this significance primarily stems from intrinsic motivation items.

To further interpret the relationship between the incubation effect on sketches and the upper alpha suppression in the incubation period, it is meaningful to look at some participants for a qualitative assessment. The following participants are positioned at both ends of the assessments. S12 has a high survey average, showed no alpha suppression, and has the highest novelty score in the incubation condition. On the other hand, S14 has the lowest survey average, an average novelty score in incubation, and the lowest novelty score on control condition among all participants and average alpha suppression. Both of them solved the Bluetooth speaker task during the incubation condition (Figure 4.104).

Figure 4.102 Sketches of S12 (on top) and S14 (at bottom) for the Bluetooth speaker task during the incubation condition

Their genealogy trees provide further insight (Appendices N). It can be seen why S12's novelty score is higher compared to S14. S12's ideas suggest unique solutions because 10 out of 16 ideas are not suggested by any other participants. Their ideas on connecting the product with other products by offering different handle solutions stand out from the rest. On the contrary, even though the variety in S14's ideas is higher, only 3 out of 15 ideas show novelty for this participant. Comparing their survey results, S12 shows a higher score compared to S14. On the other hand, while S14 faced a higher alpha suppression, S12 showed minimal alpha synchronization, which might explain the novelty in their scores: the participant (S12) could explore their semantic network more freely and create semantically distant combinations. Furthermore, S12 reported after the experiment that the speaker task was easier for his due to a focus on physical features, leading to more ideas. To him, initial ideas emerged with closed-eye brainstorming, followed by sketching. In contrast, the water bottle task was challenging for him as the focus on sustainability and material caused fixation during sketching. The participant believes additional research might have made the process more efficient. Similar to S12's closed-eye brainstorming, S14 reported that the first experience helped him think comprehensively in the closed-eye period as an effective way to reflect on design tasks. Here, incubation facilitates a diffused focus, potentially allowing the brain to restructure and widen the search within the semantic network. Their conscious engagement may have acted as a controlled exploration of their semantic network, leveraging goal-directed associative processes to uncover novel connections (Sio and Ormerod, 2009). Although both of them reported that they benefited from the incubation phase, the results of S12 show a much higher novelty score. This can be explained by the role of personal differences in goal-directed and associative search. Highly creative individuals exhibit flexible navigation through semantic networks, making larger conceptual leaps and switching between categories (Beaty and Kenett, 2023). Supporting this, the absence of alpha suppression and high creative potential scores of S12 might explain that he benefited from an incubation period by extending him search within the semantic memory possibly benefiting from her cognitive flexibility.

Figure 4.105 shows the sketches from the incubation condition, belonging to two participants who showed higher novelty scores in the control condition. While both of their survey scores are high, S05 shows no upper alpha suppression, while S09 has the highest suppression. Both of them solved the water bottle task for the incubation condition. Their genealogy trees can be found in the appendix (Appendix O).

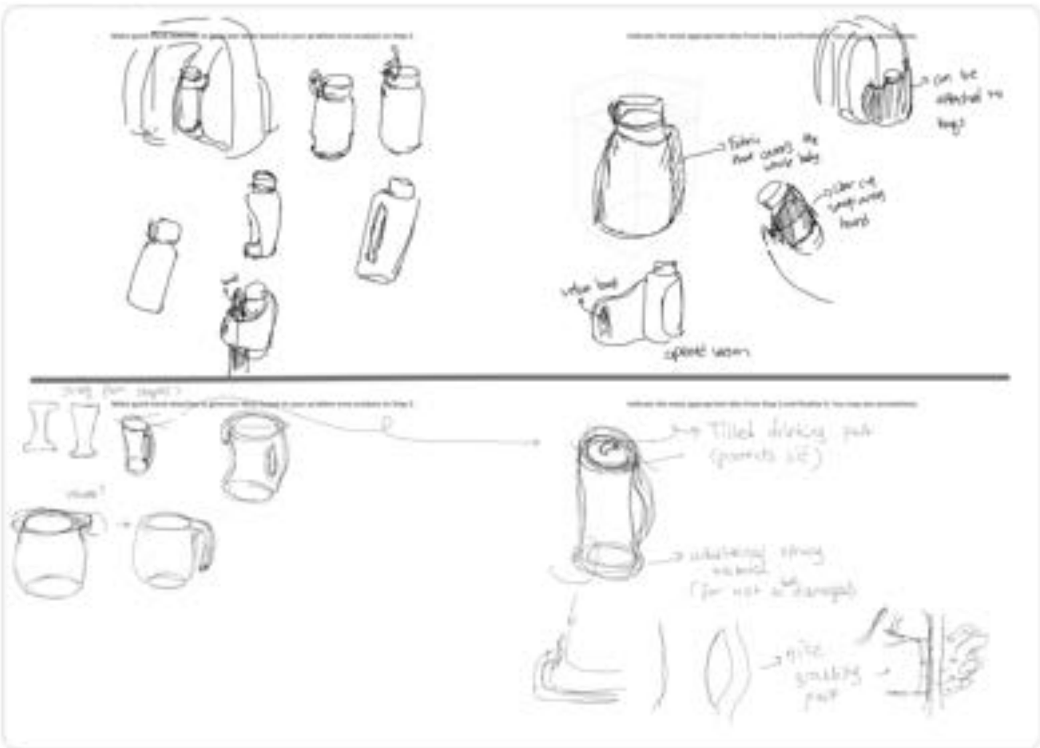

Figure 4.103 Sketches of S05 (on top) and S09 (at bottom) for the water bottle task during the incubation condition

S05's genealogy tree shows that 7 out of 10 ideas are only generated by this participant. Looking at S09's tree, it can be seen that 8 out of 12 ideas are showing novelty. Although the difference is small, visual inspection and other scores explain the higher creative performance shown by S05. It can be seen that S09 contributed to the genealogy tree by their suggestions on the various handle parts. However, interpreting visually, it can be said that the ideas are not unique and have low compliance in terms of generating solutions for a 'portable' water bottle. Moreover, the sketches on the left show similarities with the conventional containers. On the contrary, the fabric cover idea for the bottle suggested by S05 which can be used to provide different integration with other products is a unique and unlikely idea. This difference can be explained by the effect of upper alpha suppression that is seen in S09, which caused them to create conventional ideas generated by connecting closer concepts in their semantic memory. Their post-experiment reports show that both of them found their second performance (the Bluetooth speaker task in the control condition) better, not because of the design task but because of understanding the procedure. The following quote (translated from Turkish) shows S05's reflection on their design process:

"In the second part, I was slightly better at generating more diverse ideas because I had understood how the procedure worked and had thought of similar ideas in the previous topic. As a result, it became easier and quicker for me to come up with different ideas."

Similarly, S09 reflected on his process as follows (translated from Turkish):

"I think I was better during the second design process because, having experienced what to do during the first one, I was able to focus more on thinking about the problem."

Since the effect of the type of design task is uncertain, the higher novelty in the control condition might be the joint effect of the familiarization in the experimental process and the Bluetooth speaker's inherent complexity.

CHAPTER 4

CONCLUSION

This study set out to investigate the role of incubation in design creativity by exploring its relationship with creative potential, cognitive mechanisms, and creative performance. This investigation was structured around three primary research questions. The first research question sought to examine how an incubation process affects creative performance, with a specific focus on identifying which metrics differ between incubation and non-incubation conditions in the final creative outcomes. The second question aimed to explore how cognitive functions differ between resting state and incubation, further investigating how these differences influence the end products of creative tasks. The third question addressed how an individual's creative potential influences the incubation process, emphasizing the interaction between inherent creativity and cognitive engagement during incubation.

To address these questions, a mixed-methods research framework was employed, featuring a controlled lab experiment as the primary methodological approach. The study found that upper alpha suppression[4] predicts convergent thinking in the design process, which might prevent the emergence of novel ideas. The findings also revealed a positive relationship between intrinsic motivation and upper alpha suppression. The evaluation of performance in design solutions did not reveal a clear relationship between the incubation effect and creative performance, as only novelty scores belonging to one group of participants significantly benefit from an

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[4] Upper alpha suppression refers to a decrease in alpha-band (8–12 Hz) activity, typically occurring during cognitive engagement, reflecting increased cortical activity and information processing.

unfilled incubation period. Yet, this finding opens an opportunity to interpret the role of convergence in the incubation period in relation to the performance metrics as well as the importance of divergent thinking in increasing the novelty scores of products.

The overall findings indicate that controlled, conscious problem-solving, where the problem-solver actively focuses on the design task, does not enhance the novelty of outputs except if the problem solver has a good memory performance. Increased cognitive control over memory retrieval, indicated by the level of suppression, diminishes the novelty of solutions. Introducing breaks, only when one is not actively thinking about the problem within the design process proves to be beneficial by allowing an associative thinking process. This approach broadens the search within semantic memory, facilitating the construction of more distinct connections, and ultimately leading to more novel solutions. Consequently, in real-world design practice, it is recommended to incorporate breaks, ideally filled with less cognitively demanding tasks, to foster creativity and support the generation of novel ideas.

The following sections revisit each research question, synthesizing findings from the experimental data and discussing their implications in the context of the broader research objectives.

5.1 Revisiting the research questions

This section provides a concise summary of the key findings, organized around each research question. The discussion delves into how the results address the main research question and its sub-questions, highlighting the different dimensions explored in the study. This structured approach aims to contextualize the findings within the broader research framework and draw connections between the empirical results and theoretical insights.

5.1.1 Effects of incubation on creative performance

It was hypothesized to see an overall improvement in novelty, quantity, and variety scores of sketches in the incubation condition. According to the results, the incubation effect is only seen on novelty scores. Further correlations revealed that variety and quantity scores did not benefit from an incubation period. Unfortunately, the effect of incubation on novelty is rather difficult to interpret solely because a significant difference between design tasks was observed.

The design tasks were designed to follow the phases of the Double Diamond design process model, in which the participants were presented with a persona and benchmarking at the exploration phase and expected to redefine the problem within the problem space. The design tasks were determined to meet the qualities of design problems that are knowledge lean and ill-structured. Even though the same structure is followed for both problems, the significant difference in novelty scores between incubation and control conditions for the incubation-Bluetooth speaker group suggested a potential effect of the type of design task. Yet, the further correlation between novelty and alpha suppression within each group did not reveal any significance. Therefore, the result might be driven by the combined effect of incubation and the type of design task.

A possible explanation for the effect of design tasks might be the complexity inherent in the Bluetooth speaker, with its numerous components and dual role as a functional device and part of a larger technological system, which may have facilitated greater novelty through more possible combinations.

The correlation between novelty scores and suppression in upper alpha reveals a negative relationship. Shah et al. (2010) discuss the performance metrics by categorizing them: process metrics like quantity and variety are easier to improve than outcome metrics like novelty and quality. They argue that while past studies treated these metrics equally, it is now recognized that designers prioritize novelty and quality as end goals, with quantity and variety serving as means to achieve them. One potential reason for seeing a negative correlation between novelty and upper alpha suppression during the incubation condition can be explained by the goal-directed thinking process that occurred during the break. This means that participants were focused on fulfilling the task requirement and conducting a controlled and goal-directed search, which consequently caused participants to generate ideas by connecting closer concepts within the semantic network with a controlled retrieval guided by task strategies. The post-experiment survey results support this assumption since 15 out of 17 participants reported conscious thinking on the given problem during the incubation period. The two participants, who were the unconscious thinkers, were defined as outliers and were eliminated from the correlational analysis without prior knowledge.

Furthermore, the correlational analysis did not reveal any significant relationship between upper alpha suppression and other sketch performance metrics. Thus, it is concluded that alpha suppression is not a predictor of variety or quantity. As revealed by Sio and Ormerod (2009) in their meta-analysis on incubation studies, there seems to be a variety of effects unique to specific tasks and performance conditions; accordingly, novelty might be the only metric that benefits from an incubation period within the product design process.

Moreover, it should be noted that many participants reported that their performance was better in the second design phase, which corresponds to the control condition. To some, as they got used to the experimental procedure, such as the requirements of the task and the time given, they were able to plan the process and progress without any hassle.

Lastly, it is important to consider the potential effects imposed by the use of a cabled EEG system, which required participants to remain stationary within a controlled Faraday cage environment. While these constraints were essential for ensuring the precision and reliability of the EEG data, they inherently reduced the ecological validity of the study. Because the physical environment can influence creative activities by providing functional support, conveying symbolic meanings, and affecting mood, all of which are essential for fostering creativity (Dul, 2019; Amabile, 2012). Additionally, environmental cues during the incubation period can facilitate the retrieval of previously unrecognized information, thereby enhancing problem-solving capabilities (Seifert et al., 1994; Smith and Dodds, 1999; Schunn, 2005). Therefore, the controlled laboratory setting may limit the applicability of the findings to more dynamic, real-world design environments where such cues and environmental settings fostering creativity are naturally present. The environmental limitation may have limited the participants' creative potential to exhibit a good performance.

5.1.2 Effects of incubation on cognitive mechanisms

The results of the oscillatory analysis showed an upper alpha suppression (desynchronization) during the incubation condition significantly in frontal areas. Furthermore, a shift from frontal to right parietal and temporal regions along the frequency band is observed.

Alpha suppression, a phenomenon observed as a decrease in alpha power during eye-opening, has traditionally been attributed to bottom-up sensory processing driven by light stimulation (Klimesch, 1999). This explanation aligns with early EEG research, which noted large amplitudes in alpha activity, particularly in posterior brain regions, during closed eyes. However, this interpretation is challenged by findings showing that alpha suppression also occurs due to top-down activation when eyes open in complete darkness, without any visual stimulation (Klimesch, 1999). This suggests that alpha suppression is not solely tied to sensory input but may be influenced by cognitive processes. The suppression could be influenced by external sensory input (bottom-up) or by internal cognitive processes, such as focused attention (top-down) (Klimesch et al., 2007).

Further evidence supports the role of top-down mechanisms: task demands can reveal alpha suppression in frontal brain areas, especially during semantic processing tasks (Klimesch, 1999). Following this, more studies showed the relationship between alpha suppression and higher cognitive demands (Klimesch et al., 2007), with increasing cognitive load (Stipacek et al., 2003), and memory search in the semantic network (Schwab et al., 2014; Klimesch, 1999). Further, it is shown that the magnitude of suppression varies with the type of cognitive task and individual differences (Razoumnikova, 2000; Fink et al., 2011). Considering the findings from the literature, the observed alpha suppression during incubation conditions is taken as an indicator of ongoing higher-order cognition, and closer inspection into upper alpha suppression (10-12Hz) manifests search and retrieval in semantic long-term memory and memory load.

Previous studies evaluating creativity reported consistent results on the relationship between alpha activity and creativity. Studies have demonstrated higher alpha power in creative tasks performed by more creative individuals (Arden et al., 2010; Benedek, 2018), stronger frontal alpha synchronization during unusual use generation tasks (Fink et al., 2009), increased alpha activity in frontal regions to inhibit top-down mechanisms and allow internal processing (Lustenberger et al., 2015), and hemispheric asymmetry with greater alpha power in the right hemisphere during creative ideation (Martindale, 1984; Fink and Benedek, 2014).

Furthermore, earlier research demonstrates how upper alpha activity (10–12 Hz) serves as a neurophysiological marker to make distinctions between divergent and convergent thinking modes (Eymann, 2023; Mazza et al., 2023). While synchronization is approached as a marker of divergent thinking, desynchronization is seen as a marker of convergent thinking. Divergent thinking allows for more spontaneous search and original ideas, whereas convergent thinking requires focused attention and inhibitory control (Radel et al., 2015). Thus, the desynchronization observed in this study might reflect a convergent thought process that leads participants to have goal-directed attention and cognitive control over the semantic memory search. Furthermore, the observed widespread upper alpha suppression in parietal, central, and temporal regions could be attributed to the need for large-scale information retrieval and processing (Razumnikova, 2007), considering the complexity of design tasks.

However, the negative relationship between upper alpha suppression and novelty of ideas reveals that goal-directed attention might have constrained the remoteness, therefore novelty, of produced ideas. These results suggest that higher novelty requires less control to allow more associative and spontaneous search in the semantic memory.

The results further support the unconscious thinking and spreading-activation hypotheses on incubation, in which the generation of more creative ideas is supported by associative thinking. Associative thinking refers to the process where a specific stimulus or thought automatically triggers another related stimulus or thought due to its connection in semantic memory (Volle, 2018). Previous empirical studies on the incubation effect show the importance of forming remote associations by allowing unconscious and automatic associative thinking processes within the semantic memory (Dijksterhuis and Meurs, 2006; Sio and Rudovicz, 2007; Gilhooly et al., 2013; Helie and Sun, 2013).

The results also accord with the study by Cao et al. (2021) revealing that participants with lower fixation degrees exhibited task-related alpha synchronization in frontal, parietotemporal, and occipital regions, with larger synchronization in the right hemisphere. In contrast, those with higher fixation degrees demonstrated stronger alpha desynchronization in similar regions, particularly in the right hemisphere. These findings emphasize the role of alpha synchronization in inhibitory control over distractions and internally directed attention during creative tasks, while alpha desynchronization reflects repetitive solutions. These findings are in line with the associative nature of memory recall; access starts with readily available information related to recently encountered or frequently considered concepts (Martini, 2018). While earlier knowledge of similar problems is highly activated due to its stronger and more direct connections to the current situation (Sio, Kotovsky, and Cagan, 2017), the construction of closer connections has more potential. However, these familiar solutions can block better options. An incubation period during this type of fixation might help trigger a greater search in the semantic network. This also supports the incubation theories, fixation-forgetting, selective-forgetting, and attention withdrawal, advocating that an incubation phase helps bypass these stereotypes, by forgetting mental sets and enabling the discovery of unconventional solutions (Helie and Sun, 2010; Simon, 1966; Smith and Blankenship,1991; Segal, 2004).

5.1.3 Effects of creative potential on incubation

The results of the correlational analysis revealed a positive significant difference between one's creative potential and the level of upper alpha suppression ($p = 0.0444$) (Figure 3.126). Moreover, further analysis showed that the intrinsic motivation scores are significantly correlated with the upper alpha suppression in the central, parietal, and temporal channels ($p = 0.0465$). These results seem to be consistent with the studies showing the impact of motivation on creative performance (Orlet, 2008; Barr, 2014). The rising level of alpha suppression that spreads over parietal and temporal sites indicates a greater effort in solving the design problem by involving a widespread activation for those who have higher intrinsic motivation. This result aligns with Amabile's Componential Theory of Creativity (2012), which approaches intrinsic motivation as one of the elements that guides one through more creative outputs. However, since no evidence has revealed that the overall creativity of outputs benefited from any type of motivation or creative thinking skills, it seems that the widespread activation in the semantic network guided through intrinsic motivation might not guarantee an increase in creative performance.

Another explanation might be the fact that high-novelty solutions often come with significant risks, and without additional effort performed in their development, these solutions are less likely to be practical and may face early rejection (Ranjan and Chaktabarti, 2015). Therefore, participants who might have focused on the goal might have prevented extending their solution spaces.

Amabile's theory could further explain not seeing any meaningful correlation between one's motivation and creativity level of outputs. According to the theory, creative performance depends on the combination of four elements: intrinsic motivation, high creative thinking skills, domain expertise, and an environment that fosters creativity. The joint effect of the low availability of other contributors might prevent better creative performance.

Moreover, some researchers advocate that individuals with greater creativity demonstrate superior navigation of semantic memory; they explore broader associations (Beaty, 2021; Beaty and Kennett, 2023). Also, in highly creative individuals, distant components of knowledge and semantics may exhibit a high degree of interconnectivity (Volle et al., 2018). However, since the experiment does not specifically assess memory performance and the design problem-solving process encompasses a broad range of higher cognitive activities beyond memory (e.g., reasoning, critical thinking), the evaluation items used may be insufficient to fully capture or explain this relationship.

One key point for discussion is that the incubation phase scored the lowest among all creative thinking components in the CPAC test. This suggests that participants do not actively utilize incubation as a strategy or recognize its contribution to the creative process. These findings highlight the importance of raising awareness among students about the role and benefits of incubation in enhancing design outcomes.

5.2 Contributions and Implications

The empirical findings of this study provide a new understanding of the incubation effect in the design problem-solving process. In many theories of creativity, such as associative theory and dual-mechanism theories, semantic memory has an important place. However, there is not a consensus on the relationship between its presence and the type of task (i.e. it is known that semantic memory plays a role in verbal tasks, but it is unknown whether it plays a role in visual tasks) (Kennett, 2019). Furthermore, it is thought that the upper alpha activity in convergent thinking varies in accordance with the requirements of a domain (Eymann, 2024). Thus, showing how semantic memory plays a role in the design problem-solving process provides a valuable contribution to the design and cognition literature.

This study further demonstrates that the incubation effect varies depending on the type of problem being addressed. Despite both tasks representing real-world design problems in terms of ill-structuredness and open-endedness, a significant difference emerged between the design tasks used in the experiments. This finding highlights the sensitivity of the incubation effect, emphasizing that its impact cannot be universally applied across different types of problems and different domains. By revealing these task-specific variations, the study contributes to the growing body of literature on incubation, highlighting the importance of examining it in a sensitive manner and avoiding the overgeneralization of results from studies focused on specific task types.

Spontaneous brain activity, as Musso et al. (2010) highlight, reflects the brain's intrinsic functional architecture and accounts for the majority of its energy consumption, demonstrating its critical role in understanding cognitive processes. Spontaneous brain activity during the design process offers valuable insights into the neural mechanisms underlying design cognition. To date, research in design cognition has primarily focused on task-based approaches, leaving the role of spontaneous brain activity during unfilled incubation periods unexplored. This study is the first to empirically investigate how intrinsic neural dynamics contribute to design problem-solving, providing a novel perspective on the cognitive mechanisms at play.

In this thesis, the methodology section provided a detailed research journey with its ups and downs, with problems and achievements along the way, intending to provide an example for those who aim to adapt neuroscience methodologies into design research.

The analysis of genealogy trees was conducted using the C++ programming language, as detailed in the data analysis section. A custom function was developed specifically for this thesis aiming to streamline the analysis process, improving both speed and reducing the likelihood of errors. It is shared in an online medium and provided as an open-source tool to assist researchers who use similar methods.

This study demonstrated the positive impact of incubation on enhancing the novelty of ideas by facilitating a broader search within semantic memory. While further research is required to identify the optimal conditions for maximizing the effectiveness of incubation, it is suggested that breaks in the process be introduced in order to widen the search and enhance the novelty. Combined with findings from this study, which reveal a relationship between incubation and novelty, and insights from the literature highlighting its role in overcoming fixation, it is recommended to incorporate breaks into design processes, particularly for students who are more prone to fixation. For projects that demand high levels of novelty, it is advised to introduce incubation periods of varying lengths after sufficient knowledge has been acquired and the problem is clearly defined. Furthermore, it is advised to encourage students to find an occupation different than the design problem they are working on in order to let them more freely search within their memory network.

5.3 Limitations

The limitations can be addressed from two perspectives; the limitations caused by adapting a neuroimaging method into design research and the limitations that arose from employing complex tasks in a neuroscientific study. Regarding the former, the lack of ecological validity and the time restriction form the limitations. As for the latter, the manual markering and employing complex problems form the limitations.

A major limitation that is also mentioned in the discussion section was the use of EEG with cables surrounding the participant's scalp, combined with the movement restrictions and the controlled Faraday cage environment. These factors, while necessary for accurate data collection, limit the ecological validity of the findings.

Another limitation of this experimental design is the time constraint. Extended recording sessions would likely increase participants' discomfort and introduce movement-related artifacts into the data, making it necessary to identify an appropriate session length. However, the design process generally requires flexibility and sufficient time to thoroughly explore the problem space, generate ideas, and iterate on potential solutions. While the duration of a design process varies depending on the expectations and constraints of a design brief, as well as the complexity of the problem, restricting designers to a linear, 12-minute process may have limited the depth and creativity of their outputs. Also, limiting the incubation period to 4 minutes might restrain the novelty level of generated ideas.

One limitation of the methodology was the reliance on manual marking during data recording. As explained in the data collection section (3.4.2), technical issues encountered during setup and the time required to resolve them led to the decision to proceed with manual marking. This approach resulted in slight variations in the recorded data length for each participant, requiring the researcher to select a standardized length across all participants, which in turn led to some data loss.

One issue with the study was the noise that is produced by the wireless connection between the drawing tablet and its pen. Fortunately, the noise could be eliminated with a bandstop filter during the preprocessing of the EEG data. However, it is recommended to use a wired drawing tablet if it is intended to be employed in an EEG study.

One limitation of this study was the number of participants being employed in the experiments. Although the number of participants was sufficient even after the elimination of participants for a neuroscience experiment, the results from self-reports and sketches are limited in terms of statistical methods and generalizing the effect of the results.

Another limitation that makes the interpretation harder of the results is the influence of the design tasks themselves. As discussed in Section 2.2.1, the tasks were selected based on those specific criteria and the following: familiarity to individuals, the absence of expertise requirements, and similar sizes and forms. Despite these considerations, the findings highlight the need for selecting design tasks that are even more closely aligned, particularly in terms of technological complexity and the inherent number of components.

5.4 Suggestions for further studies

This study provided valuable insights into the mechanisms underlying the incubation period but was limited in investigating the conditions that facilitate its effectiveness. Future research could focus on identifying the optimal conditions for a successful incubation period, including factors such as its ideal duration, the nature of design and incubation tasks, the timing of incubation within the design process, and the length of the preincubation phase. It is important to seek enhancement of ecological validity to support the natural flow of thinking in the creative process and to ensure findings apply to real-world settings.

Beyond understanding the cognitive foundations of incubation, it is crucial to explore how this mechanism can be effectively integrated into the design process. Research should investigate practical strategies for structuring incubation periods, determining the phases of the design workflow where they are most beneficial, and optimizing their application to support idea generation. Additionally, understanding how to align incubation practices with varying design contexts and individual creative styles could maximize their potential impact on fostering innovation.

As discussed in 4.1.2, an important consideration is that the temporal and spatial characteristics of cognitive activity can vary greatly depending on task demands and an individual's creative potential. One’s approach to a problem is strongly influenced by their experience, motivation, cognitive abilities, and environment which can, in turn, shape the processes used to arrive at a solution. Moreover, design problems are inherently complex and differ significantly from well-structured, closed-ended problems. As a result, research on related phenomena, such as insight and incubation, that focuses on other types of problems may not fully apply to product design. Therefore, future research could explore how cognitive processes differ depending on the specific types of design problems, along with the consideration of the contributors being addressed.

Furthermore, it would be interesting to assess the effect of individual differences in terms of semantic memory structure, particularly how the organization and connectivity of semantic networks influence creative thinking. For instance, individuals with more interconnected networks may construct semantically distant associations, facilitating the generation of novel ideas. Conversely, those with less interconnected networks might rely more heavily on executive control processes, such as strategic planning and inhibition, to navigate their semantic memory (Beaty and Kennett, 2023; Benedek et al., 2023). Investigating these differences could illuminate whether creativity arises from the interaction of these factors or whether distinct cognitive mechanisms independently drive innovative thought.

An interesting research focus might be located at the intersection of fixation and insight. Although insight problems and design problems have common elements, such as requiring creativity and problem-solving skills, they differ in their nature, goals, and processes. Thus, exploring the relationship and role of insight in overcoming fixation can provide insight into cognitive mechanisms.

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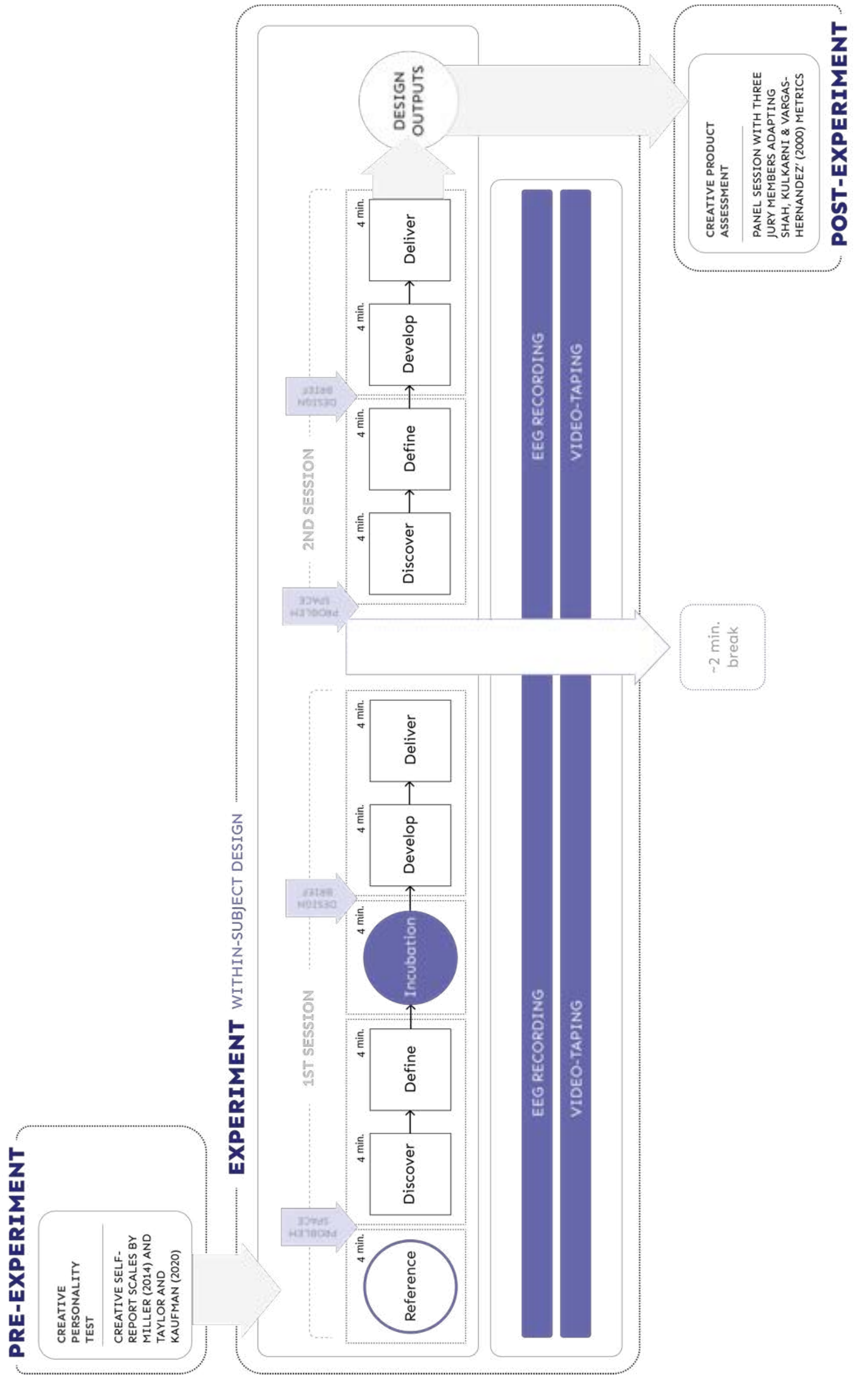
APPENDICES

A. Research Framework



B. Experiment timeline

Step 1: Doğa OR Ekin

Step 1 (con't): Doğa OR Ekin

Step 1: Design brief for Doğa OR Ekin

Step 2 information

Step 2: Miro workspace

Incubation period

Ten participants will undergo incubation condition for the design brief of Doğa, and other ten will undergo incubation condition for the design brief of Ekin. During incubation there will be fixation cross at the screen. The order of the screens will be as follows:

Step 3 information

Step 3: Miro workspace

Step 4 information

End of the first experiment OR end of all

C. Consent Form

<u>Araştırmaya Gönüllü Katılım Formu</u>

Bu araştırma, ODTÜ Endüstriyel Tasarım Bölümü'nde doktora öğrencisi olan Yaprak Deniz Yurt'un tez çalışması kapsamında, Naz A.G.Z. Börekçi danışmanlığında ve Tolga Esat Özkurt eşdanışmanlığında yürütülmektedir. Bu form sizi araştırma koşulları hakkında bilgilendirmek için hazırlanmıştır.

Çalışmanın Amacı Nedir? Araştırmanın amacı tasarım bilişine dair nörobilim araçları aracılığı ile bilgi edinebilmektir. Araştırmaya katılmayı kabul ederseniz, sizden beklenen, size verilen iki tasarım föyü doğrultusunda size tanınan sürede tasarım fikirleri üretmenizdir. Bu araştırmanın içerdiği çalışma ortalama olarak 2 saat sürmektedir. Çalışmaya hazırlık ortalama 45 dakika sürecek olup, anketler ve deney (iki tasarım süreci) ortalama bir saat, iki tasarım süreci arasındaki mola ise ortalama 15 dakika sürecektir.

Bize Nasıl Yardımcı Olmanızı İsteyeceğiz? Araştırma süreci anket ve deneyden oluşmaktadır. İlk aşamada EEG cihazının kurulumu gerçekleşecektir. Bu aşamadan sonra özellikle başınızı olabildiğince sabit tutmanız beklenecektir. Ancak tablet kullanımında elinizi hareket ettirmenizin bir sakıncası bulunmamaktadır. İlk olarak, likert ölçeğinde iki anketi bilgisayar ortamında yanıtlamanız beklenmektedir. Bu anketler 5 dakika kadar sürmektedir. Daha sonra size bir tasarım föyü verilecek ve belirtilen basamakları takip etmeniz, problem alanı için fikir üretmeniz beklenecektir. Süreç, "Double Diamond" tasarım modeline göre bölümlenmiş olup, başlangıç ve bitiş süreleri deney esnasında bildirilecektir. Bu sürecin sonunda yaklaşık olarak 15 dakikalık bir mola verilecektir. Deneyin ikinci aşamasında, ilk aşamadaki süreç farklı bir tasarım problemi ile tekrarlanacaktır. Deneyde yapacağınız çizimler Miro arayüzünde yapılacak olup herhangi bir özel yetkinlik gerektirmemektedir. Deney süresince yapmanız gereken iş adımları ve sizden beklenenler bilgisayar arayüzü aracılığı ile size aktarılacaktır. Deney süresince tasarım problemleri üzerinde çalışırken bilişsel aktivitelerinize dair EEG cihazı ile veri toplanacaktadır. Araştırmanın sonraki aşamasında analiz edilmek üzere çalışma esnasında video ve ekran kaydı yapılacaktır. Çalışma kapsamında kişisel bir bilgi talep edilmemektedir.

Sizden Topladığımız Bilgileri Nasıl Kullanacağız? Araştırmaya katılımınız tamamen gönüllülük temelinde olmalıdır. Anketlerde ve tasarım sürecinde sizden kimlik veya kurum belirleyici hiçbir bilgi istenmemektedir. Cevaplarınız tamamıyla gizli tutulacak, sadece araştırmacılar tarafından değerlendirilecektir. Katılımcılardan elde edilecek bilgiler toplu halde değerlendirilecek ve bilimsel yayımlarda kullanılacaktır. Sağladığınız veriler gönüllü katılım formlarında toplanan kimlik bilgileri ile eşleştirilmeyecektir.

Katılımınızla ilgili bilmeniz gerekenler: Araştırma ODTÜ Enformatik Enstitüsü bölüm laboratuvarında yapılacaktır. Bilişsel veri toplamak için kullanılacak olan Elektroensefalografi (EEG) beyindeki elektriksel aktiviteyi kafatası etrafına yerleştirilen elektrotlar aracılığıyla kaydeder. Bu yöntemin sağlık üzerinde herhangi bir riski, olumlu ya da olumsuz bir etkisi bulunmamaktadır. Deney süresince, beyin sinyallerinin hareketten etkilenmemesi için başınızı ve vücudunuzu mümkün olduğunca sabit tutmanız beklenmektedir. Elektriksel sinyallerin elektronik cihazlar ve çevre gürültüsünden etkilenmemesi için deneyler laboratuvarda bulunan Faraday kafesinin içerisinde gerçekleştirilecektir. Faraday kafesi, içerisinde masa, bilgisayar ve koltuk bulunan ufak bir oda niteliğindedir. Bilgisayar ile A5 boyutundaki çizim tableti aracılığıyla etkileşim kurulacaktır. Deney süresince takip etmeniz gereken adımlar ve her adım ile ilgili detaylı bilgi o esnada bilgisayar aracılığı ile size aktarılacaktır. Katılım sırasında sorulardan ya da herhangi başka bir nedenden ötürü kendinizi rahatsız hissederseniz cevaplama işini yarıda bırakıp çıkmakta serbestsiniz. Böyle bir durumda çalışmayı uygulayan kişiye, çalışmadan çıkmak istediğinizi söylemeniz yeterli olacaktır. Çalışma sonunda, bu araştırmayla ilgili sorularınız cevaplanacaktır.

Araştırmayla ilgili daha fazla bilgi almak isterseniz: Bu çalışmaya katıldığınız için şimdiden teşekkür ederiz. Veri toplama aşamasının tamamlanmasının ardından araştırma ile ilgili daha detaylı bir bilgi verilecek ve varsa, sorularınız cevaplanacaktır. Daha fazla bilgi almak isterseniz Yaprak Deniz Yurt [redacted] ile iletişime geçebilirsiniz.

Yukarıdaki bilgileri okudum ve bu çalışmaya tamamen gönüllü olarak katılıyorum.

(Formu doldurup imzaladıktan sonra uygulayıcıya geri veriniz).

İsim Soyad	Tarih	İmza
	----/----/-----	

D. Confidentiality agreement

<u>Gizlilik Anlaşması</u>

Değerli katılımcı, bu doktora tez çalışması kapsamında yürütülecek olan deneyler 20 farklı katılımcı ile gerçekleştirilecektir. Deneylerin sonuçlarının anlamlandırılabilmesi için her bir katılımcının deneyimlediği sürecin mümkün olduğunca aynı olması gerekmektedir. Aynı zamanda, katılımcıların süreç ve tasarım problemleri ile ilgili deney öncesinde araştırmacı tarafından sunulan bilgilerden daha fazla ve daha detaylı bilgiye sahip olması, toplanan verinin güvenilirliğini riske sokar. Bu sebeple, size sunulan tasarım problemlerinin ve süreç ile ilgili detayların gizli tutulması verilerin doğruluğu açısından büyük önem taşımaktadır. Bu belge, size verilen tasarım problemlerini ve süreç ile ilgili bilgileri deney dizisi bitene kadar gizli tutacağınıza dair bir sözleşme niteliğindedir.

Deneyde bana sunulan tasarım problemleri ve deney süreçleri ile ilgili bilgileri Eylül 2022 tarihine kadar gizli tutacağımı ve deneye daha sonra katılımcı olarak katılacak arkadaşlarım ile paylaşmayacağımı taahhüt ediyorum.

Ad Soyad:

İmza:

Tarih:

Yer:

E. Post-participation information form

Katılım sonrası bilgi formu

Bu araştırma, ODTÜ Endüstriyel Tasarım Bölümü'nde doktora öğrencisi olan Yaprak Deniz Yurt'un tez çalışması kapsamında, Naz A.G.Z. Börekçi danışmanlığında ve Tolga Esat Özkurt eşdanışmanlığında yürütülmektedir. Araştırmanın amacı, kuluçka aşamasının altında yatan bilişsel fonksiyonların normal bir dinlenme aşamasından ne şekilde farklılaştığını ve bu sürecin tasarım çıktılarının yaratıcılığına olan etkisini anlamaktır.

Tasarım sürecinde etkili bir şekilde konumlandırılan bir kuluçka sürecinin yeni fikirlerin üretimini desteklediği (Kirjavainen ve Höltta, 2020) ve çıkan fikirlerin yaratıcılığını artırdığı (Dodds, Ward, ve Smith, 2004; Hernandez, Shah, ve Smith, 2010; Tsenn vd., 2014) ortaya konulmuştur. Aynı zamanda, problem alanının keşfedilmesinden sonra ve yeni fikir üretme aşamasına geçmeden önce konumlandırılan bir kuluçka aşamasının tıkanmayı engellediği düşünülmektedir (Shah, Kulkarni, ve Vargas-Hernandez, 2000). Dolayısıyla, kuluçka aşamasının tasarım çıktılarına daha etkili olacak şekilde kullanımını desteklemek amacıyla bu çalışmada (1) kuluçka aşamasının normal bir dinlenme aşamasından nasıl farklılaştığı, (2) kuluçka aşaması ile çıkan tasarım fikirlerinin yaratıcılık metrikleri arasındaki ilişki ve (3) katılımcıların yaratıcılık yaklaşım ve motivasyonlarının kuluçka aşamasındaki bilişsel aktiviteye olan etkisi araştırılmaktadır.

Çalışmanın başında kuluçka aşamasının etkisini anlamanın amaçlandığının belirtilmemesinin nedeni, katılımcılardan tasarım sürecinin ortasında dinlenmesi beklendiğinde, problem alanına bilinçli olarak odaklanmasını ve çözümler üretmeye koşullanmasını engellemektir.

Bu çalışmadan alınacak ilk verilerin 2022 sonunda elde edilmesi amaçlanmaktadır. Elde edilen bilgiler sadece bilimsel araştırma ve yazılarda kullanılacaktır. Bu araştırmaya katıldığınız için tekrar çok teşekkür ederiz.

Araştırmanın sonuçlarını öğrenmek ya da daha fazla bilgi almak için aşağıdaki isimlere başvurabilirsiniz.

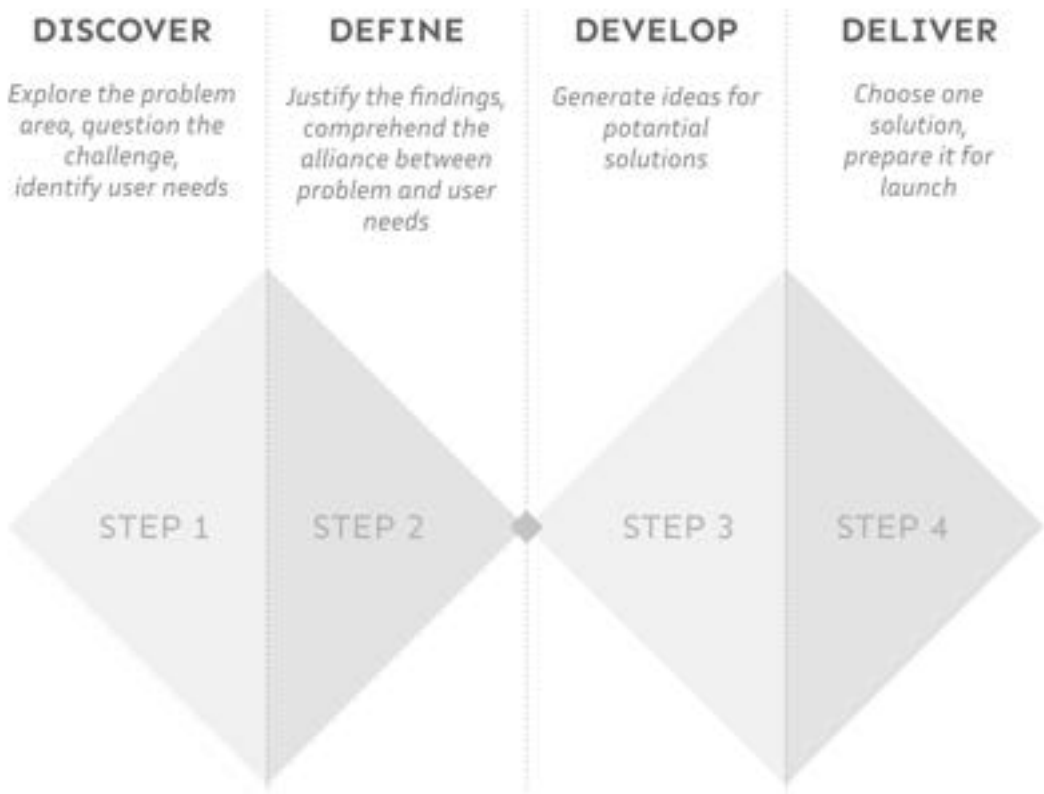
Yaprak Deniz Yurt [redacted]

Çalışmaya katkıda bulunan bir gönüllü olarak katılımcı haklarınızla ilgili veya etik ilkelerle ilgi soru veya görüşlerinizi ODTÜ Uygulamalı Etik Araştırma Merkezi'ne iletebilirsiniz.

e-posta: [redacted]

F. Information sheet about the design process

The experiment consists of two design processes in which you will be given a different design problem and are expected to generate ideas following the Double Diamond design process. You can see the phases of the process as follows:



The Double Diamond model represents the design process with four main phases of divergent and convergent thinking. During the first step, you will be given a design brief describing a problem area. In this step, you are expected to explore the problem area. In the second step, you are expected to choose a problem to move on based on the information and materials given in the first step. In the third step, we hope you generate solutions for the problem with quick sketches. In the fourth step, you are expected to choose and finalize the most appropriate idea. You may use annotations in this phase.

The nature of problems will be open-ended but familiar. You will not need additional research apart from the information given to you during the discovery phase. Each step lasts around five minutes. At the end of each step, you will be informed about where you are and what the next step will be.

You need to click X when you read the instructions and are ready for the next step. All information and flow will be presented through the screen. You will not be able to return the previous screens once you pass.

The researcher will not be in the room where you are positioned.

Please keep in mind to stay still. Have fun!

G. Self Reports: Creative Trait Motivation Scale (Taylor and Kaufman, 2020)

Think about times when you have been creative in the [*domain specific instructions*]. Using the scale below, indicate to what extent each of the following items presently corresponds to one of the reasons why you engage in [*domain*] creativity.

Does not correspond at all		Corresponds a little	Corresponds moderately	Corresponds a lot		Corresponds exactly
1	2	3	4	5	6	7

I engage in [*domain*] *creativity...*

1. Because of the sense of well-being I feel.
2. Because I want to be viewed more positively by certain people.
3. Because of the pleasant sensations I feel.
4. Because I do not want to disappoint certain people.
5. Even though I believe it is not worth the trouble.
6. Because it allows me to make interesting discoveries.
7. Because it will help me become the person I aim to be.
8. Because of the pleasure I feel as I become more and more skilled.
9. Although it does not make a difference to me whether I do or not.
10. Because of the satisfaction I feel in trying to excel.
11. Because I experience enjoyable feelings.
12. Because I would feel bad if I did not.
13. Although I do not see the benefit in it.
14. Because it is important to me.
15. Because I would beat myself up for not doing so.
16. In order to attain prestige.
17. Because of the pleasure I feel outdoing myself.
18. Even though I do not have a good reason for doing so.
19. Because I would feel guilty for not doing so.
20. Because I enjoy what I am doing in the moment.

Domain-specific instruction variations
…arts (painting/drawing, designing jewelry, photography etc.)…
…everyday sense (entertaining small children, tinkering with a design, solving personal problems etc.)…
…sciences (designing experiments, computer sciences, logic/puzzles etc.)…

Scoring
Values for items belonging to each subscale are averaged to yield three scores: intrinsic motivation, extrinsic motivation, and amotivation.

Intrinsic motivation items
1, 3, 6, 7, 8, 10, 11, 14, 17, 20

Extrinsic motivation items
2, 4, 12, 15, 16, 19

Amotivation items
5, 9, 13, 18

H. Self Reports: Cognitive Mechanisms Associated with Creativity (Miller, 2014)

<u>Response Options</u>

(1) Never (2) Rarely (3) Sometimes (4) Often (5) Always

<u>Idea Manipulation</u>

Joining together different elements can lead to good ideas.

Combining multiple ideas can lead to effective solutions.

Looking at a problem from a different angle can lead to a solution.

Thinking about more than one idea at the same time can lead to a new understanding.

If I get stuck on a problem, I look for details that I normally would not notice.

<u>Imagery / Sensory</u>

I try to act out potential solutions to explore their effectiveness.

Becoming physically involved in my work leads me to good solutions.

If I get stuck on a problem, I visualize what the solution might look like.

While working on something, I often pay attention to my senses.

Imagining potential solutions to a problem leads to new insights.

While working on something, I try to fully immerse myself in the experience.

<u>Flow</u>

When I am intensely working, I don't like to stop.

I can completely lose track of time if I am intensely working.

While working on something I enjoy, the work feels automatic and effortless.

If I am intensely working, I am fully aware of “the big picture.”

Metaphorical/Analogical Thinking

If I get stuck on a problem, I try to apply previous solutions to the new situation.

Incorporating previous solutions in new ways leads to good ideas.

If I get stuck on a problem, I make connections between my current problem and a related situation.

If I get stuck on a problem, I look for clues in my surroundings.

Idea Generation

While working on a problem, I try to imagine all aspects of the solution.

While working on something, I try to generate as many ideas as possible.

If I get stuck on a problem, I try to take a different perspective of the situation.

I get good ideas while doing something routine, like driving or taking a shower.

If I get stuck on a problem, I ask others to help generate potential solutions.

In the initial stages of solving a problem, I try to hold off on evaluating my ideas.

Incubation

When I get stuck on a problem, a solution just comes to me when I set it aside.

I get solutions to problems through my dreams.

I get solutions to problems when my mind is relaxed.

I. Genealogy tree of the water bottle control condition comprised with keywords derived from Function-Behavior-Structure analysis

```
|__ Ideas
    |__ Body
    |   |__ Form
    |   |   |__ Rigid
    |   |   |   |__ D Shaped
    |   |   |   |   |__ Asymetrically Sculpted
    |   |   |   |   |__ Straigth
    |   |   |   |__ Conical
    |   |   |   |__ Symmetrical Amorphous
    |   |   |   |__ Cylindrical
    |   |   |       |__ Dumbell
    |   |   |       |   |__ Straight
    |   |   |       |   |__ Curvy
    |   |   |       |__ Conical Hourglass
    |   |   |       |__ Asymetrically Sculpted
    |   |   |       |__ Curved Axis
    |   |   |       |__ Straight
    |   |   |__ Flexible With Bellows
    |   |__ Orientation
    |       |__ Right Side Up
    |       |__ Upside Down
    |   |__ Labels
    |   |__ Protection
    |       |__ Non Slipness
    |       |   |__ Grippy Base
    |       |   |__ Grippy Body
    |       |__ Insulation
    |   |__ Materials
    |       |__ Metal
    |       |   |__ Stainless Steel
    |       |   |__ Aluminium
    |       |__ Plastic
    |           |__ Plastic PP
    |           |__ Rubber
    |       |__ Composite
    |       |__ Biodegradable
    |__ Components
        |__ Handle
        |   |__ Form
        |   |   |__ Loop
```

```
|       |       |       |__ Unspecified
|       |       |       |__ Fabric
|       |       |__ Hoop
|       |       |__ Like A Bag Handle
|       |       |__ Strap
|       |__ Connection
|               |__ Connected To Body
|               |__ Connected To Lid From Both Sides
|               |__ Connects Lid And Body
|               |__ Connects Body Faces Together
|__ Spout
        |__ Foldable
        |__ Central Fixed Short
|__ Lid
        |__ Connection With Body
        |       |__ Nested
        |       |__ Hinged
        |       |__ Screwed
        |__ Form
                |__ Angled
                |__ Spout Lid
                |__ Long And Deep
        |__ Leakproof
                |__ Lock Mechanism On Top
                |__ Slicon Gasket
                |__ Bump Under Lid
|__ Cover
        |__ Coat Cover
        |__ Multiple Faced Cover
        |__ Faces Held With Strap Cover
|__ Integration
        |__ Inserted In Backpack Pocket
        |__ Connects To Backpacks Side With Its Straps
```

J. Genealogy tree of the water bottle incubation condition comprised with keywords derived from Function-Behavior-Structure analysis

```
|__ Ideas
    |__ Body
    |   |__ Form
    |   |   |__ Rigid
    |   |   |   |__ Amorphous
    |   |   |   |   |__ Asymmetrical
    |   |   |   |   |__ Symmetrical
    |   |   |   |__ Cylindrical
    |   |   |       |__ WithHandle
    |   |   |       |   |__ Mug
    |   |   |       |   |__ Kettle
    |   |   |       |   |__ BeerGlass
    |   |   |       |   |__ Ear Like Bumps
    |   |   |       |__ Without Handle
    |   |   |           |__ Curvy
    |   |   |           |   |__ Dumbell
    |   |   |           |   |__ Hourglass
    |   |   |           |__ Straight
    |   |   |               |__ SlimThin
    |   |   |               |__ Long
    |   |   |               |__ Standart
    |   |   |           |__ Sculpted
    |   |   |               |__ Asymmetrical
    |   |   |               |__ Symmetrical
    |   |   |__ Flexible Flattened Collapsed
    |   |       |__ Bellows
    |   |       |__ Spiral
    |   |       |__ Polygonal
    |   |__ Patterns
    |       |__ Form
    |       |__ Graphical
    |       |__ No Pattern
    |   |__ Materials
    |       |__ Steel
    |       |__ Plastic Recyclable
    |   |__ Protection
    |       |__ Impact Resistant
    |       |__ Double Wall Insulation
    |__ Components
        |__ Handle
        |   |__ Form
        |   |   |__ Rigid
        |   |   |   |__ Open Ended
```

```
 |   |   |   |   |__ At One Side
 |   |   |   |   |__ At Both ide
 |   |   |   |__ Closed
 |   |   |       |__ Additional Material
 |   |   |       |__ Hole In The Body
 |   |   |__ Flexible
 |   |       |__ Form
 |   |       |   |__ Loop
 |   |       |   |__ Hoop
 |   |       |__ Connection
 |   |           |__ On Body
 |   |           |__ On Lid
 |   |__ Anti Rollover
 |       |__ Handle Attachment To Backpack Zip
 |       |__ Handle Extends To The Ground
 |__ Spout
     |__ Central Fixed Short
     |__ Central Fixed Long
 |__ Lid
     |__ Connection With Body
     |   |__ Hinged
     |   |__ Screwed
     |   |__ Magnetic
     |__ Form
         |__ Angled Tilted
         |__ With A Hole
         |__ Shallow
         |__ Long And Deep
     |__ Leak Proof
         |__ Lock Mechanism OnSide
         |__ Silicon Gasket
         |__ Bump Under Lid
 |__ Fabric Cover
|__ Integration
    |__ Inserted In Backpack Pocket
    |__ Connects To Backpack
        |__ To Backpacks Zip
        |__ To Backpacks Side With Velcro
        |__ To Backpacks Shoulder Strap
        |__ To Backpacks Side Pocket With Handle
```

K. Genealogy tree of the Bluetooth Speaker control condition comprised with keywords derived from Function-Behavior-Structure analysis

```
|__ Ideas
    |__ Body Enclosure
    |   |__ Form
    |   |   |__ Rigid
    |   |   |   |__ Amorph
    |   |   |   |   |__ Nature Inspired
    |   |   |   |   |   |__ Mineral Shaped
    |   |   |   |   |   |__ Cloud Form
    |   |   |   |   |   |__ Flower Form
    |   |   |   |   |__ Spiral
    |   |   |   |   |__ Sculpted
    |   |   |   |       |__ To Grasp
    |   |   |   |       |__ To Connect Body And Top
    |   |   |   |           |__ Single Conical
    |   |   |   |           |__ Double Cones Connecting From Small Surface
    |   |   |   |           |__ Double Cones Connecting From Long Surface
    |   |   |   |           |__ Double Cones On Top Of Each Other
    |   |   |   |       |__ To Form A Lid
    |   |   |   |   |__ Symmetrical Pebble Shape With Two Domes
    |   |   |   |   |__ Dough Like
    |   |   |   |__ Circular Rounded
    |   |   |       |__ Pebble Shaped
    |   |   |       |__ Torus
    |   |   |           |__ Straight
    |   |   |           |__ Drop Section Torus
    |   |   |       |__ Spheroid
    |   |   |       |__ Cylindrical
    |   |   |           |__ Capsule
    |   |   |           |__ Straight
    |   |   |       |__ Angled Conical
    |   |   |   |__ Angular
    |   |   |       |__ Trapezoid
    |   |   |       |__ Hexagonal
    |   |   |       |__ Prismatic
    |   |   |           |__ Flat Surface With Wavy Sides
    |   |   |           |__ Cube
    |   |   |           |__ Rectangular
    |   |   |           |__ DSectioned Prism
    |   |   |       |__ Multi Faceted Pyramide Form
    |   |   |__ Flexible
    |   |       |__ Foldable
    |   |       |__ Dough Like Form
    |   |__ Dimensions
```

```
|       |__ Colors
|               |__ Nature Inspired Graphical Pattern
|               |__ Two Color Options
|       |__ Lights
|               |__ From All Edges Round Shapes
|               |__ At The Front
|               |__ From Inner Edges Triangular Shape
|       |__ Orientation
|               |__ Self Standing
|               |       |__ On Body Or Base
|               |       |__ Strap Turns Into A Triangle Base
|               |__ Vertical Orientation
|               |__ Horizontal Orientation
|               |__ Hangable
|               |__ Wearable
|               |__ Rocking On Surface
|__ Components
        |__ Charging Port
        |__ Sound Output
                |__ At Front Face
                |       |__ Spherical Area With Dotted Pattern
                |       |__ Circular Area With Hole Pattern
                |__ At Three Faces Cylindrical Shape With Horizontal Slit Pattern
                |__ At All Faces Triangular Shape With Scribble Pattern
        |__ Buttons
                |__ Form
                |       |__ Separate
                |       |       |__ Circular
                |       |       |__ Triangular
                |       |__ Embossed
                |       |__ Touch Control
                |__ Position
                        |__ On Front
                        |__ On Top
                        |__ On Inner Surface
                |__ Function
                        |__ Play Pause
                        |__ Go Back Forward
                        |__ Not Specified
                        |__ Turn On Off
                        |__ Volume Up Down
                        |__ Bluetooth Connection
        |__ Feedback Lights
        |__ Display With Flip Feature
        |__ Handle
                |__ Rigid
                |       |__ Magnet
```

```
|       |__ U Shaped Clip
|               |__ Fixed
|               |__ Removable Metal
|       |__ Mounted
|               |__ Edgy
|               |__ Curvy
|__ Flexible
        |__ Strap
        |       |__ Detachable
        |       |__ Fixed
        |               |__ Single Strap To Insert On Belt
        |               |__ Double Fabric Strap To Hang On Backpack Handle With
A Stopper Detail
        |__ Rope
        |__ Loop
        |__ Elastic Cord
                |__ To Insert On Belt
                |__ To Wrap Around Wrist
|__ Integration
        |__ Pairing With Other Speakers Without Contact
        |__ Modular Components
        |__ Mobile App
```

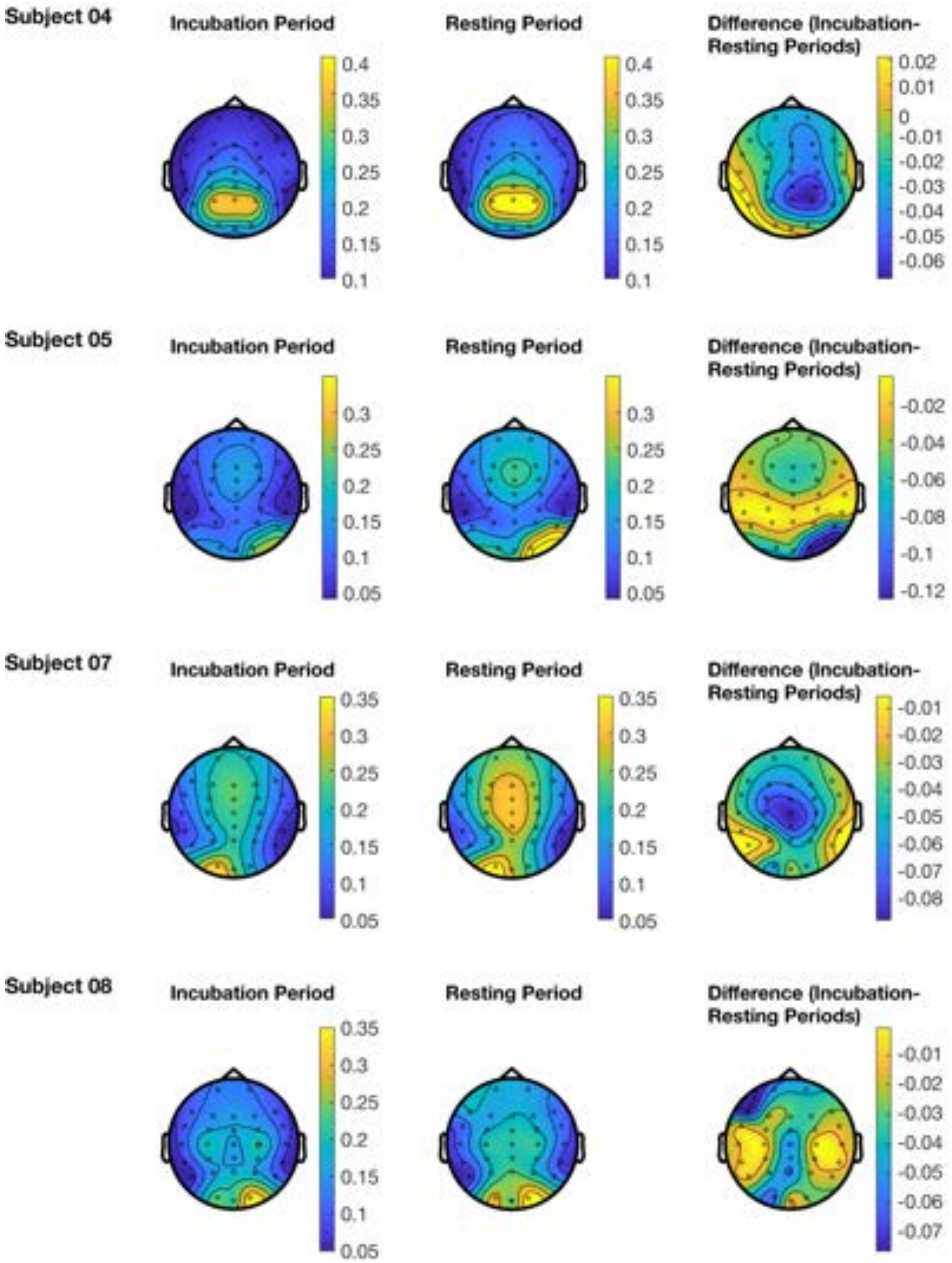
L. Genealogy tree of the Bluetooth Speaker incubation condition comprised with keywords derived from Function-Behavior-Structure analysis

```
|__ Ideas
    |__ Body Enclosure
    |   |__ Form
    |   |   |__ Rigid
    |   |   |   |__ Prismatic
    |   |   |   |   |__ Rectangular
    |   |   |   |   |   |__ Multi-Surface
    |   |   |   |   |   |__ Curved Surfaces
    |   |   |   |   |   |__ Flat Surfaces
    |   |   |   |   |__ L Shaped
    |   |   |   |   |__ Triangular
    |   |   |   |   |__ Hexagon
    |   |   |   |__ Conical
    |   |   |   |__ Semi Spherical
    |   |   |   |__ Cylindrical
    |   |   |   |   |__ Hourglass
    |   |   |   |   |__ Asymmetrical
    |   |   |   |   |__ Straight
    |   |   |   |   |__ Semi Cylindrical
    |   |   |   |__ Purse Like
    |   |   |   |__ Sculpted
    |   |   |       |__ For Other Functions
    |   |   |       |__ To Mount A Strap
    |   |   |       |__ To Grasp Body
    |   |   |       |__ To Form Feet
    |   |   |__ Flexible
    |   |       |__ Wrappable
    |   |       |__ Bean Bag
    |   |__ Dimensions
    |   |__ Colors
    |   |__ Orientation
    |       |__ Self Standing
    |       |__ Vertical Orientation
    |       |__ Horizontal Orientation
    |       |__ Hangable
    |__ Components
        |__ Sound Output
        |   |__ All Around With Grid Pattern
        |   |__ At Front Face
        |       |__ Amorph Curvy Area With Dotted Pattern
        |       |__ Circular Shape
        |       |__ Rectangular Shape
        |           |__ Vertical Slits
```

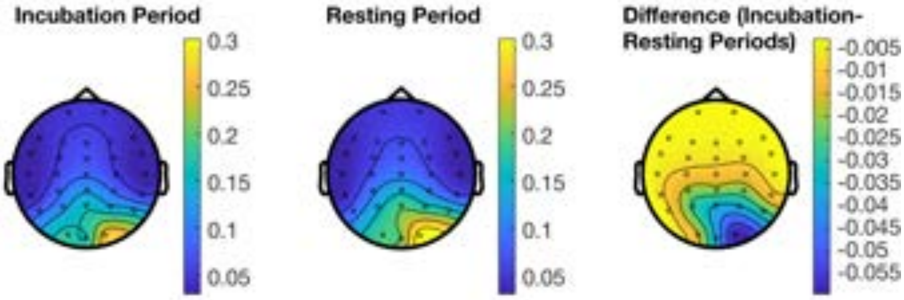
```
|                    |__ Horizontal Slits
|                    |__ Grids
|             |__ Triangular Shape
|                    |__ Circular
|                    |__ Parallel Lines
|                    |__ Grids
|      |__ At Top And Bottom
|__ Battery
|__ Charging Port
|__ Buttons
       |__ Form
       |      |__ Separate
       |      |      |__ Circular
       |      |      |__ Triangular
       |      |      |__ Square
       |      |__ Embossed
       |__ Function
              |__ Volume Up Down
              |__ Turn On Off
              |__ Bluetooth
              |__ Unspecified
              |__ Play Pause
       |__ Position
              |__ On Top
              |__ On Side
              |__ On Front
|__ Displays
       |__ Touchscreen
       |      |__ Underneath Horizontal Surface
       |      |__ Facing On A Vertical Surface
       |__ Screen
|__ Handle
       |__ Flexible
       |      |__ Rope
       |      |__ Strap
       |             |__ To Hang On Backpack Handle
       |             |__ To Hang On Shoulder
       |             |__ To Insert Hand
       |                    |__ Flat With Sculpted Body
       |                    |__ Edgy And Rubber
       |                    |__ Curvy With Grippable Section
       |             |__ To Insert On Belt
       |                    |__ With Magnet
       |                    |__ With Mechanical Fasteners
       |             |__ To Attach
       |      |__ Body Turns To Handle
       |             |__ To Wrap On Bag Strap
```

```
|         |__ To Wrap On Bike Frame
|     |__ Loops
|         |__ To Insert On Belt
|__ Rigid
    |__ Hook
    |__ Clip
        |__ To Attachon Belt On Top
        |__ To Hang On One Side
    |__ Mounted
|__ Carrying Case
    |__ To Pack Modules
    |__ To Carry
        |__ With Short Strap To Carry By Hand
        |__ With Long Strap To Hang On Shoulder
|__ Integration
    |__ Interaction With Other Products
    |     |__ Pairing
    |     |     |__ More Than One Speakers
    |     |     |__ More Than One User
    |     |__ Phone Docking Station
    |     |__ Collect Sound From Different Instruments
    |__ Configuration
        |__ Male Female Configuration
        |     |__ Vertical Division
        |     |__ Horizontal Division
        |__ Connection Slots At Side
        |__ Pins
        |__ Side By Side
```

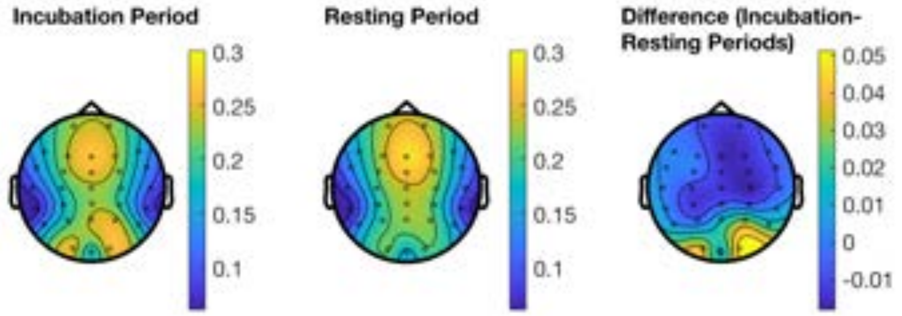
M. Subject-specific alpha band (8-12Hz) power representations



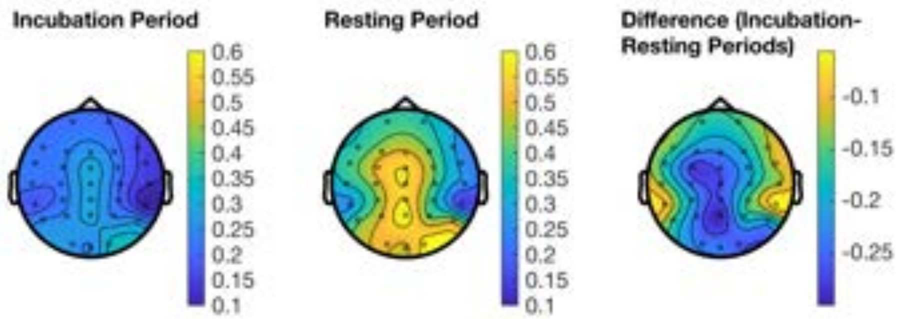
Subject 09



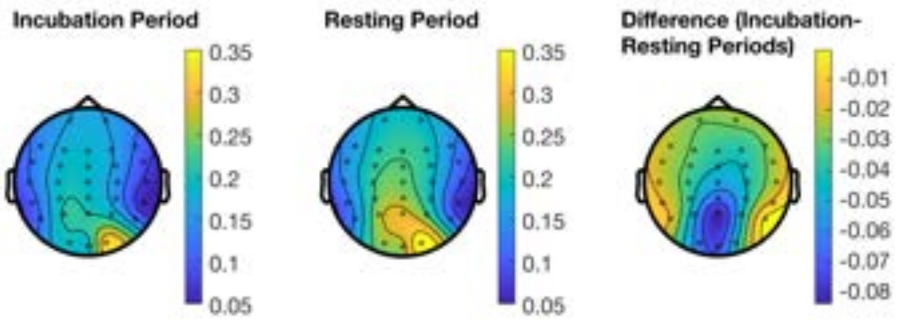
Subject 10

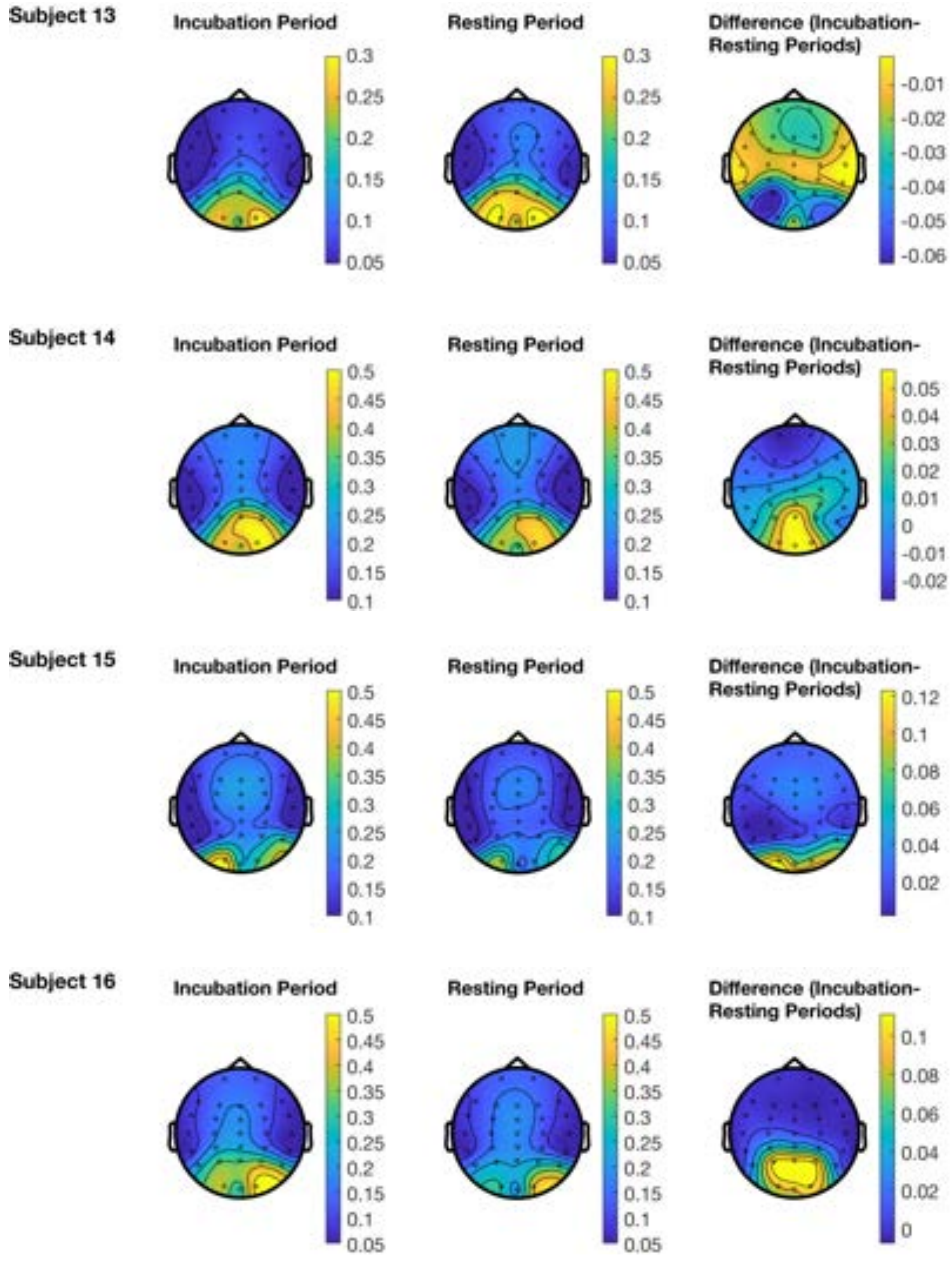


Subject 11



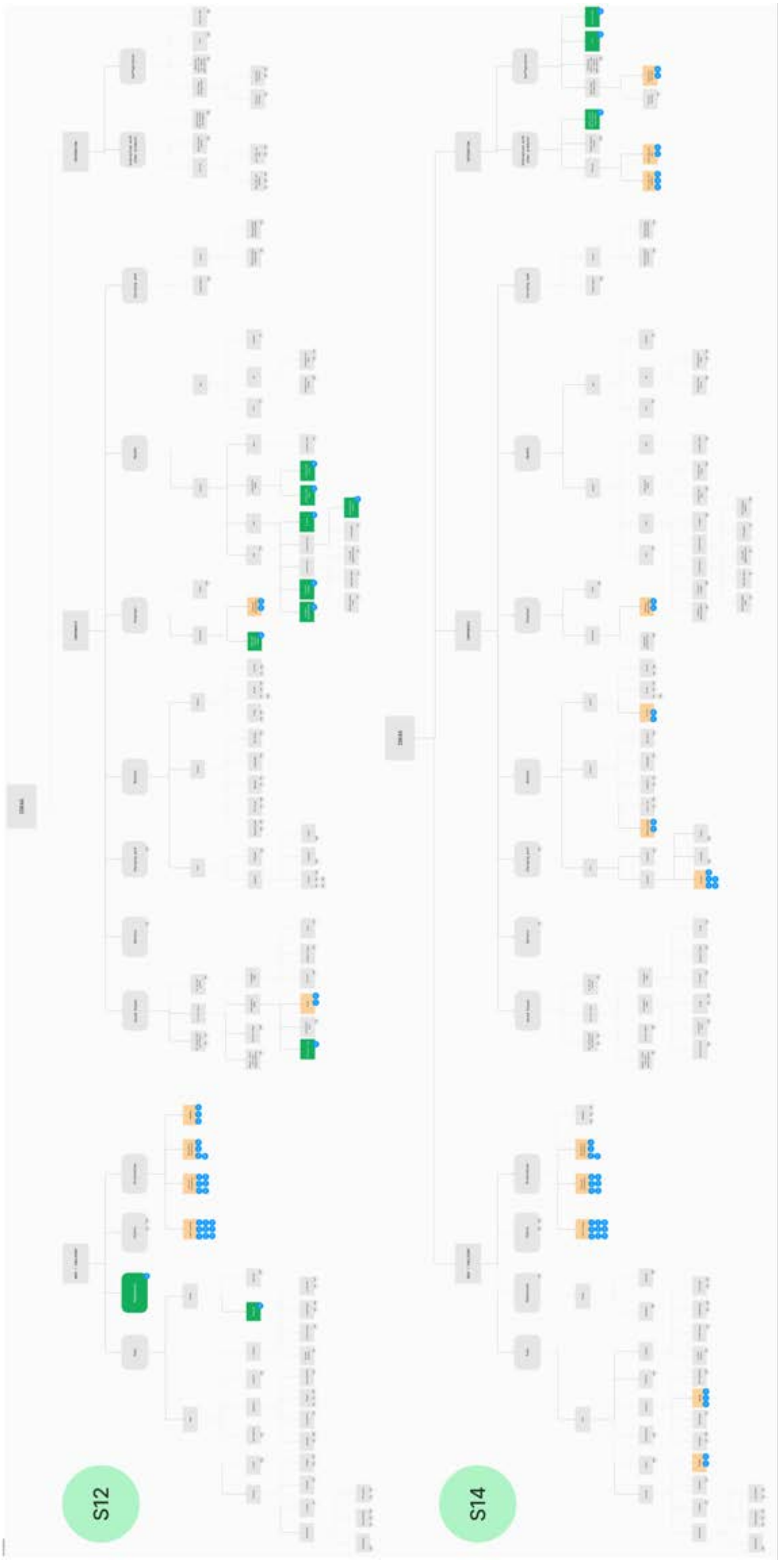
Subject 12



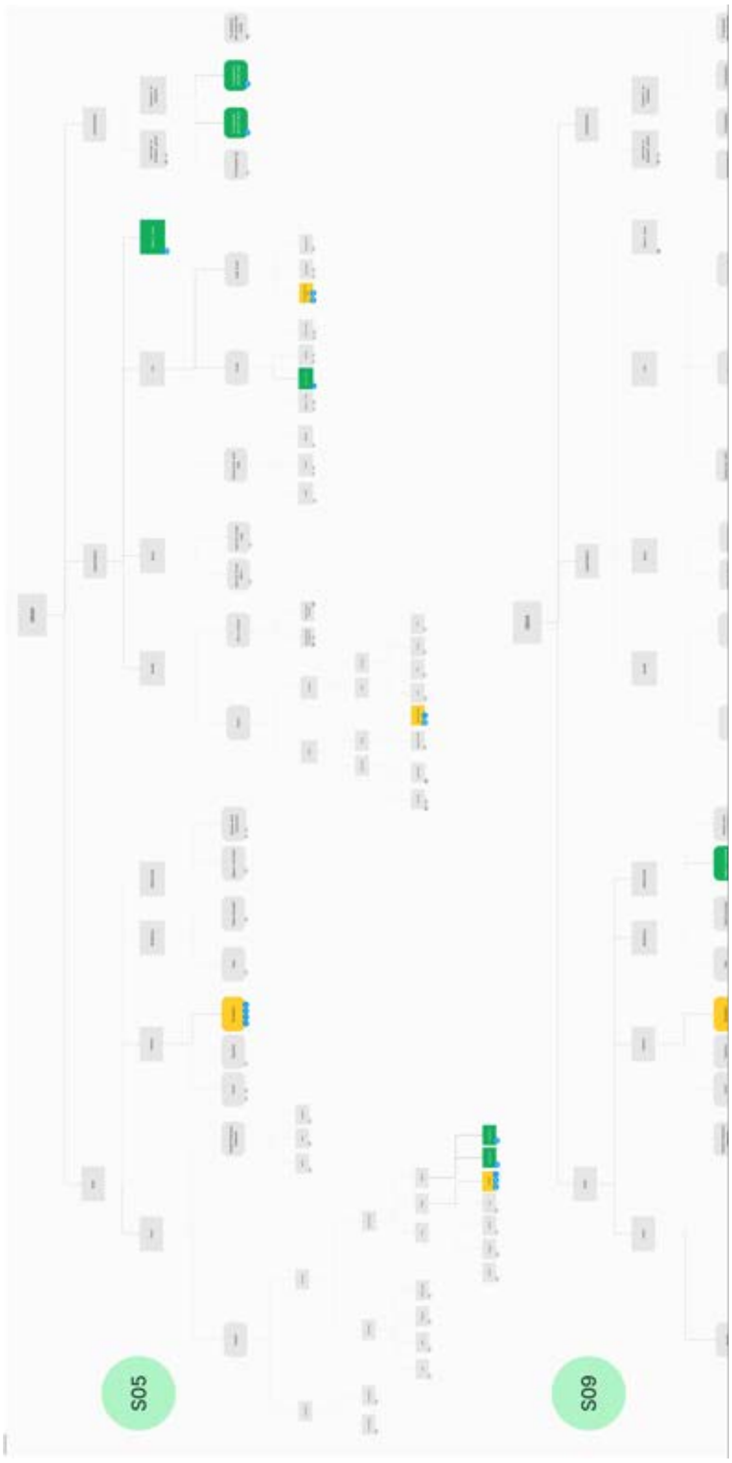


Subject 13
Incubation Period
0.3
0.25
0.2
0.15
0.1
0.05
Resting Period
0.3
0.25
0.2
0.15
0.1
0.05
Difference (Incubation-Resting Periods)
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
Subject 14
Incubation Period
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
Resting Period
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
Difference (Incubation-Resting Periods)
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
Subject 15
Incubation Period
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
Resting Period
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
Difference (Incubation-Resting Periods)
0.12
0.1
0.08
0.06
0.04
0.02
Subject 16
Incubation Period
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
Resting Period
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
Difference (Incubation-Resting Periods)
0.1
0.08
0.06
0.04
0.02
0

N. Genealogy trees of S12 and S14 for the incubation condition



O. Genealogy trees of S05 and S09 for the incubation condition



CURRICULUM VITAE

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Degree	Institution	Year of Graduation
MS	Anadolu University Industrial Design	2019
BS	Anadolu University Industrial Design	2015
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FOREIGN LANGUAGES

Advanced English

PUBLICATIONS

1. Yurt, Y. D., Ozkan, I., & Yargın, G. T. (2020). Tasarım Stüdyosu Eğitiminde Fikir Üretme Sürecinde Kullanılan Yöntemlerin ve Karşılaşılan Problemlerin Öğrenci Bakış Açısıyla İncelenmesi. In UTAK 2020-Dördüncü Ulusal Tasarım Araştırmaları Konferansı: Tasarım ve Öngörü.
2. Yurt, Y. D., & Öztürk, N. (2021). Tasarım Sürecinin Model Bazında Tarihsel Olarak İncelenmesi. In Mimarlık Planlama ve Tasarım Alanında Araştırma ve Değerlendirmeler - I.
3. Yurt, Y. D., & Toros, S. (2022). UX in Design Studio: Insights from Students' Experiences of a Structured Design Process. In The IIER International Conference.
4. Yurt, Y. D., Börekçi, N. A. G. Z., & Özkurt, T. (2022, May). How incubation affects the creative performance: An ongoing neuroimaging study of incubation in the design process. Poster presented at the 7th Meeting of The Society for the Neuroscience of Creativity.
5. Yurt, Y. D., Börekçi, N. A. G. Z., & Özkurt, T. (2023, September). Yaratıcılık Sürecinde Kuluçka Periyodunun Nörogörüntülemesi. Poster presented at 1. Ulusal Nörogörüntüleme Kongresi.