Using Cognitive Training to Boost Innovative Thinking Skills for Higher Education Students

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Table of Contents

Foreword/ Acknowledgements

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Summary

In recent years, a stronger emphasis has been given to the development of innovative thinking skills. Those skills consist of the sub-skills of Divergent (DT) and Convergent Thinking (CT). Both DT and CT even though interconnected, follow contradicting thinking patterns, which poses a challenge to educators to teach them simultaneously. A possible solution for overcoming this challenge is using cognitive training, whereby the learners' attention is focused on the cognitive processes followed when conducting an action. To test the hypothesis that cognitive training on innovative thinking skills could have an impact on DT and CT skills a quasi-experimental quantitative study was conducted. To test this hypothesis Mann-Whitney U tests were utilized to test the between-group comparison, and Wilcoxon Signed Rank tests for within-group comparisons. The results indicate no significant effect of cognitive training on CT and DT. However, it is possible that the strict CT requirements led the focus of the students towards a single solution fulfilling the requirements of the assignments, rather than true innovative outputs. This finding signifies the need for further investigation of the CT skills focus of most educational systems, and the impact that this focus might have on the innovative thinking skills of the students. Finally, the current study could serve as a pilot for understanding DT and CT skills development in educational settings.

Introduction

Problem Statement

The latest developments in the labour market, set high requirements for future employees. They need to not only be trained on skills necessary at their current positions but also to be able to accommodate the constant developments in their careers (Hero et al., 2017). Moreover, it is important to adjust to the new developments in the industry, especially given the fast pace at which these developments occur (Saabye et al., 2022). This is especially relevant when new products, ideas and/or processes need to be developed (Chell & Athayde, 2011). This is why innovative thinking skills are highly appreciated. They equip the employees with skills that allow them to reach those new products, ideas and/or processes (González-Salamanca et al., 2020; Ocasal et al., 2022).

Innovative thinking skills allow people to think creatively and to produce outcomes that differ from previous iterations (West et al., 2012). Innovative thinking skills consist of two sub-skills, namely Divergent (DT) and Convergent Thinking (CT) (Bingölbali & Bingölbali, 2022). The first, DT, allows the learners to develop a multitude of creative options and/or solutions for a problem. DT is close to the brainstorming process (Baruah & Green, 2023). The second process, CT, leads to selecting the most appropriate solution for a problem, resonating with problem-solving cases (de Vink et al., 2021). Both skills are important for developing innovative thinking (Cropley, 2006) and are strongly interconnected (Zhu et al., 2019). Both DT and CT skills are trainable and can be taught during the education of future employees (Bingölbali & Bingölbali, 2022).

Simultaneously training design thinking (DT) and critical thinking (CT) skills can be quite challenging. Despite being interconnected, these two skills require different thinking patterns, and students often show a stronger predisposition for one over the other (Lubart, 2016). Some learners excel in DT, constantly generating new creative ideas but struggle to narrow them down to a single solution. On the other hand, those with stronger CT skills tend to focus on a single, easily accessible solution and may not explore multiple options (de Vink et al., 2021).

Previous research proves that, due to their large differences, training DT and CT skills requires different approaches (Cortes et al., 2019; González-Salamanca et al., 2020; Ranabahu et al., 2020). Many studies attempted to define proper teaching methods for teaching DT and CT as integrated parts of innovative thinking skills with little success (González-Salamanca et al., 2020). An approach that has not yet been used is cognitive training (Braßler & Schultze, 2021). This approach proposes that the mere knowledge about the mental processes occurring within the brain when learning something new can support the learning process (Chapman et al., 2017). The approach is also supported by research regarding metacognitive skills in education (Ruiz-Martín & Bybee, 2022).

Hence, it is hypothesized that providing cognitive training could allow learners to simultaneously develop their DT and CT skills while developing each of them independently as required due to their differences (West et al., 2012). To achieve this goal the DT and CT skills will be made explicit (Kim et al., 2023; Sun et al., 2020), offering an understanding of the connection and interaction between the processes (De Vries & Lubart, 2017; Sun et al., 2020). This knowledge could support them to self-direct their learning into improving their innovative thinking skills, by focusing where needed (Braßler & Schultze, 2021).

Innovation

The demands of the labour market require future employees not only trained on the current job description skills but also prepared to adjust to the needs of their future careers (Hero et al., 2017; González-Salamanca et al., 2020; Ocasal et al., 2022; Saabye et al., 2022). The current students should learn not only to be able to perform their professional tasks properly but also to be able to respond creatively to the needs of the market by designing innovative products, services and approaches fitting the needs of the ever-changing work fields (Chell & Athayde, 2011). The intense technological developments in the job market require agility in educational developments following the fast-paced changes in industry in order to bridge the *skills gap* that arises due to the acceleration in developments in industry (Kilic-Bebek et al., 2023). This phenomenon, also termed *the innovation gap*, is a gap between education and innovation in the job market (Hero et al., 2017).

Scholars from the educational sciences of the last years call the field of research investigating the skills gap as *21st-century skills* (Erol, 2021), or *soft skills* (González-Salamanca et al., 2020). Because those skills are meant to respond to the current needs and requirements of the job market as well as to anticipate the ones to come, they are considered to build upon the sustainability of the current and future knowledge society (González-Salamanca et al., 2020; Ocasal et al., 2022). 21st-century skills are often considered complementary to the basic skills offered at any educational institution (González-Salamanca et al., 2020). It is important to underline, however, that the specific skillset required per work field differs (Rios et al., 2020). Hence, the same contemporary soft skills might be relevant for one position, but not for another.

Central among the 21st-century skills are innovative thinking skills (Kennedy & Sundberg, 2020). Many studies have attempted to define *innovation*, with various results stretching from more concrete to more holistic definitions (Hero et al., 2017), with all of them including novelty to some extent (Peñalver et al., 2018). However, novelty on its own is not enough. The outcome has to meet the criterium of usefulness parallelly (Peñalver et al., 2018). Hence, the definition that most closely resonates with the needs of the current study is the one of Sawer (2006), whereby innovation is defined as the outcome of an innovation process whereby created ideas are transformed into a single outcome.

The innovation process involves rapid prototyping, testing, manufacturing, and implementing new or revised products or services (Hero et al., 2017). Thereby, new innovative outcomes are developed from scratch or older versions of products or services are revised (Peñalver et al., 2018). To provide innovative outcomes new ideas need to be developed in an innovative brainstorming session (Baruah & Green, 2023); which, consequently, will be narrowed down and tested to meet specific requirements (de Vink et al., 2021). In this approach, innovation is not only creating a new outcome but rather paving the pathway to a new approach or way of thinking about reaching the expected outcome (O'Connor, 2012). Furthermore, the outcomes of an innovation process can take many forms, such as products, services, approaches, thinking patterns, strategies and more (Hero et al., 2017; Kennedy & Sundberg, 2020; Ocasal et al., 2022; Rios et al., 2020).

On the practical level, introducing novel and applicable ideas is relevant in many instances. Traditionally, it has been considered relevant for everyday problem-solving (Duval et al., 2022), as well as for application in the fields of Arts, Humanities and Education (Mu et al., 2022; Rios et al., 2020; Sun et al., 2020), under the form of creativity. However, innovative thinking, as the most applied and entrepreneurial form of the skill, is a highly appreciated skill that can improve employability in a range of work fields (Brennan et al., 2023; Kim et al., 2023). Tangible examples of this notion could be having a creative approach towards problem-solving or being able to innovate a technological advancement in the field of science (Kim et al., 2023; Sun et al., 2020), design and engineering (Sun et al., 2020), health and business (Habib et al., 2024). In other words, in every field where repurposing and problem-solving are central, innovative thinking appears to be an important skill (Abu-Akel et al., 2020).

Before delving deeper into the specific skills related to innovation, it is important to place a disclaimer regarding some complexities that innovation faces in academic literature. More specifically, the term innovation is considered equal to *creativity* by some academic studies (Avcı & Durak, 2023; Rios et al., 2020), while elsewhere a clear distinction from creativity is made (Peñalver et al., 2018; Scott, 2015). For instance, according to an analysis by González-Salamanca et al. (2020), innovation and creativity are intertwined in most of the literature. On the contrary, according to West and Farr (1989), creativity is merely the proposal of a new idea, while innovation imposes its application (Khandwalla & Mehta, 2004). Following this line of thought, scholars present innovation as the result of creative thinking (Braßler & Schultze, 2021). Other researchers propose that there is a difference between the two concepts regarding the level of individual engagement. For the needs of this article, no distinction will be made between innovation and creativity, as the two concepts appear intertwined for most of the academic literature (Peñalver et al., 2018).

Innovative Thinking Skills

Innovative thinking skills are the skills that a person needs to reach an innovation (Sun et al., 2020). These skills allow an individual to think critically, and innovatively and develop solutions different than other previously already established solutions (Avcı & Durak, 2023). Other scholars define innovative thinking as the cognitive process whereby a person generates original, and appropriate outputs for a given problem. Those outputs can have different forms, such as products, processes, theoretical frameworks and approaches (West et al., 2012). In other cases, the outcomes of innovative thinking skills can comprise improvement of previously applied and successful ideas (Sun et al., 2019).

Regardless of the correct and accurate definition, it is a fact that being able to generate original and appropriate solutions is a necessary skill for multiple work fields (Fernandez-Cosials & Gonzalo Jimenez, 2016; Sun et al., 2020). A recent literature review identified at least 10 disciplines whereby innovative thinking is of paramount importance, namely entrepreneurship, business and management, science and technology, economics, psychology, education, organization, human resources, medicine and health care, sociology and political sciences (Morad et al., 2021). The evident need for innovative thinking skills stretches beyond financial and practical benefits and into the students' commitment to learning and their active class participation (Avcı & Durak, 2023). The more innovative the students are allowed to be in their classrooms, the more motivated they tend to be; and the more motivated they are, the more tangible positive outcomes they achieve (Barak, 2009x; Kotkas et al., 2017).

When developing innovative thinking skills, a person gains a multitude of parallel sub-skills that are relevant for generating innovative outcomes. For instance, one should learn to generate new original ideas (Avcı & Durak, 2023) as well as learn how to apply those to each problem or question (Uyangör, 2020). To reach this result, the development of other skills is required as well. For instance, a person needs to develop good analytical and organizational skills, such as planning, evaluating and reporting (Sun et al., 2020). Furthermore, an innovator needs to be able to question previous versions of the item that aims to be innovated upon (Duval et al., 2022). Furthermore, the development of innovative thinking skills can be influenced by many external parameters. Such parameters can be personal characteristics of a person, such as personality, learning difficulties and talents. Other parameters can be external to the person, such as family and school circumstances, and living conditions (Sun et al., 2019).

Most of those parameters are not controllable, given that they comprise elements external to the person, e.g. situational or environmental parameters. However, some of the core parameters influencing innovative thinking skills are cognitive factors (De Vries & Lubart, 2017), which are trainable and can be understood after study. As innovative thinking is a complex mental process (Avcı & Durak, 2023), it is important to define some core elements that define the final innovative thinking outcomes.

Divergent and Convergent Thinking

Some frameworks determining the cognitive processes underlying innovative thinking skills have been developed. For instance, the framework of Lubart et al. (2013) divides innovative thinking skills into cognitive sources, or the mental capacity to be innovative, and conative abilities, or personal characteristics allowing a person to be innovative. Cognitive sources are for instance divergent, analytical, associative thinking, mental flexibility and selective combination. Conative resources are tolerance to ambiguity, risk-taking, openness, intuitive thinking and motivation to create. However, the most used framework to comprehend innovative thinking is the distinction between divergent thinking (DT) and convergent thinking (CT) (Bingölbali & Bingölbali, 2022). Both CT and DT are considered higher-order thinking skills, connected to creativity, problem-solving and innovative thinking (Mangaroska et al., 2021).

DT has been investigated more than CT (Sun et al., 2020), as it is considered the source of innovation (Karakelle, 2009). DT is the cognitive process of generating complex, creative and diverse ideas from a simple input (West et al., 2012), which can also be defined as a brainstorming process (Baruah & Green, 2023). In problem solving this skill is utilized to generate large amounts of possible solutions (de Vink et al., 2021). DT is a complex process, including several sub-skills, namely fluency, originality and flexibility (Barak et al., 2019; Sun et al., 2020). *Fluency* is the number of ideas one can produce. *Originality* is the uniqueness of those ideas in comparison to other ideas. *Flexibility* is the ability to produce ideas that spread among different categories, diverse from each other (Karakelle, 2009; Runco, 2011; Sun et al., 2020; de Vink et al., 2021).

The least investigated process of CT involves the concentration of ideas in a single solution. CT is characteristic in properly defining a problem and its basic influencing parameters (Barak et al., 2019); as well as in focusing one's scattered and abstract ideas towards a concrete and concentred application (Bingölbali & Bingölbali, 2022), or a single correct solution for problem-solving cases (Gabora, 2018; de Vink et al., 2021). In other words, CT could also be defined as idea refinement (Baruah & Green, 2023), or idea focusing (Barak, 2009). CT is very important in innovation, as this ensures the practical application of creative thinking by transforming abstract ideas into tangible results for a specific case (Duval et al., 2022), and finding solutions tailor-made to the needs of a problem (de Vink et al., 2021). Scholars support this notion, by proposing that DT is mostly connected to creativity only, and not CT (Yang et al., 2023).

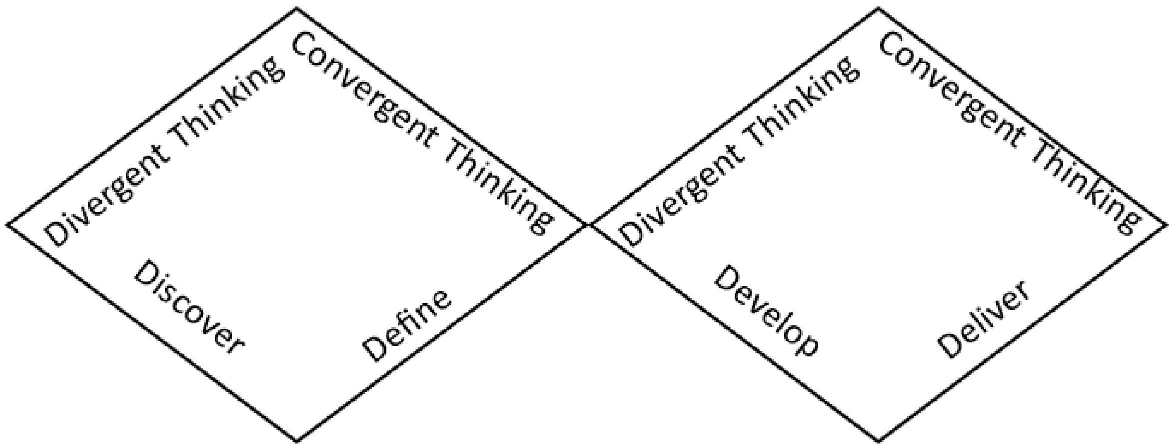
Given that CT is less investigated than DT (Duval et al., 2022; Gangi, 2018; de Vink et al., 2021), its main parameters are more difficult to define. CT can be broken down into sub-processes where a person establishes connections between concepts (association), changes, or decomposes original ideas to fit the needs of new circumstances (decomposition) and integrates new information to already existing schemata (combination with adjustment) (Sun et al., 2019; Sun et al., 2020). It is still important to underline that completely diverse parameters have been utilized by other academics (de Vink et al., 2021). The most used division separates CT in correctness, completeness and innovativeness (Avcı & Durak, 2023; Cheng et al., 2021; Lubart et al., 2013). Correctness is the number of suitable solutions generated for a given problem. Completeness is the extent to which a solution meets all the relevant requirements. Innovativeness is the novelty of a solution in comparison to already existing solutions or comparison to solutions of others.

The connection between DT and CT has also been long investigated, without reaching a common agreement among academics. A study by De Vries and Lubart (2017) proposes that the two skills might counteract each other's development. DT and CT have proved to even have different developmental processes (Duval et al., 2022). More specifically, CT develops steadily from the age of eight, while DT forms unstably from the age of six. More interestingly the two processes seem to counteract each other, with CT's development starting when DT's development decreases (Duval et al., 2022). However, other studies propose that the two processes are complementary to each other, with CT not being able to properly develop without DT, and the counter (Javaid & Pandarakalam, 2021). Finally, other studies propose that there are shifts between DT and CT, which might be related to the personal characteristics of an individual, rather than external parameters (Duval et al., 2022).

Regardless of the disagreement, all academics agree that the two concepts are interconnected (Sun et al., 2020). Kim et al. (2023) connect CT and DT in the *double diamond model (DD)* (See Figure 1). According to DD, DT is firstly used to *discover* the problem in large, and then CT is used to *define* the topic parameters. Consequently, possible solutions are *developed* using DT, and the most suitable is selected using CT and *delivered*.

Figure 1

Double Diamond model from Kim et al., (2023)



Note. DT & CT processes have been added to the original Discover-Define-Develop-Deliver model for clarity.

Teaching Innovative Thinking Skills

Considering innovative thinking as a competence, it is logical to consider that innovation can be taught and thereby trained as other competencies (Hero et al., 2017; Sun et al., 2020). Training this competence might not only ensure temporal creative ideas but also develop an innovative mindset that can boost innovation in the long term (Ocasal et al., 2022). This approach practically serves the need for adaptability and innovative thinking in the future. Training individuals on the cognitive processes that underline innovative thinking, as well as providing students with tools on how to train those skills can have positive outcomes on their performance on innovative thinking tasks (Sun et al., 2020).

Consideration.

There is a distinction between *innovation in education* and *innovation as a learning material*. Innovation in education is the process whereby new innovative approaches to educating students in various educational fields are introduced (Fuad et al., 2020). In the last centuries, many creative educational methods have been developed that support students learning, such as teaching through comics, flip-the-classroom, and even the utilization of invading technologies such as virtual reality and escape room settings of the learning material (Martens & Crawford, 2019). All those methods have been proven to support the learning process of the students by providing alternative sources of information acquisition and practice opportunities that are not normally covered by the classic lecture modules. The focus of the current study is on the second concept, which is the one of innovation as a learning object. In the latter case, the process of innovation is taught, skills related to innovative thinking are trained and the practice of applying innovative techniques to learning is introduced to the students learning only about innovation (Braßler & Schultze, 2021).

Antecedents for Innovative Skills Development.

Before delving into the methods that can promote innovative thinking, it is important to comprehend the antecedents of innovative thinking skills development, as well as the main parameters that impact this learning. The following paragraphs shortly account for this need.

The process of innovation starts usually within a stage of fuzziness, whereby uncertainty, equivocality and complexity are strongly present (Stevens, 2014). This initial state, as well as the first steps in the innovation process, can impact the DT and CT process of an individual and impact the outcome of the innovation. Thereby personal characteristics of the learners such as motivation, personality and prior knowledge, have a pivotal role in leading the thinking process (Sak & Oz, 2010). Of secondary, yet high importance are also environmental factors, such as the teacher's behaviour (Sun et al., 2019), an environment that stimulates innovative thinking (Barak et al., 2019)

There is an interplay between those personal characteristics and the environmental factors influencing the learning process. A safe and supportive learning environment providing opportunities for trial-and-error, with an attentive teacher giving feedback and guidance can enhance students' self-belief and motivation, which consequently influences their persistence and motivation, as well as their performance (Sun et al., 2019). Similarly, if the students acquire the relevant content knowledge on a topic, they can produce more rich problem-solving activities (Williams, 2013). On the contrary, if the learning material is too unfamiliar to the learner, their motivation to be involved and their performance is lowered (Avcı & Durak, 2023). Yet, if the learners are too familiar with the learning material and no challenges are posed to their thinking, which can also hinder divergent thinking (Baer, 2020; Sun et al., 2020).

Another parameter influencing innovative thinking is the learning group. Innovation can be an individual or a group process. In the first case, a person rests on their competencies

(Peñalver et al., 2018), while in the second, the diverse perceptions and ideas are moulded together in interaction (Peñalver et al., 2018). Working in teams, especially in groups from different disciplines, has many benefits. In particular, it can improve knowledge synthesis and consequent innovation development (Kilic-Bebek et al., 2023). It can also enhance the generation of novel ideas and their practical applications, due to the diversity of backgrounds and ways of thinking (Braßler & Schultze, 2021). Furthermore, the learners can use each other as a support system, by answering questions, boosting motivation when lacking and providing a better understanding of the task and process requirements (Zhou, 2018). Finally, as the complex demands of the industry nowadays require collaboration among disciplines, receiving interdisciplinary working experience through learning can benefit the future career of the learner (Kilic-Bebek et al., 2023). However, understanding how innovative thinking skills development is still not comprehended by scientists to its full potential (Sun et al., 2020).

Teaching approaches.

As innovative thinking belongs among the newly identified 21st-century skills, there is no common agreement on the most suitable approaches to teaching those skills (González-Salamanca et al., 2020). Training innovative thinking skills appears more challenging than the formal curriculum learning material since they do not follow a stable curriculum, but a problem-solving open-ended approach (Ranabahu et al., 2020). Hence training those skills requires a different approach than the rest of the course subjects (González-Salamanca et al., 2020). Finally, in developing those novel skills, the learner is expected to gradually engage with more complex problems and more deliberate practice, a phenomenon characterised by a conscious effort to improve the cognitive skills of practising with a task and exceed previous performance levels (Persky & Robinson, 2017).

Many methods have been developed to teach the subskills of innovative thinking skills independently (Sak & Oz, 2010). Some examples therefrom are the training of DT through music practices (Gangi, 2018), drama and theatre training (Karakelle, 2009; Karwowski & Soszynski, 2008), multimedia tools (Doron, 2017), as well as the training of CT through logical thinking based on testing opposing statements (Sak & Oz, 2010), alternative perspectives (Doron, 2017), and computer-based cognitive mapping approaches (Sun et al., 2020). The successful approach to teaching DT and CT separates the two skills in the learning process but does not offer a holistic approach to teaching those skills together.

Several studies have attempted to develop a holistic teaching approach. The instructional framework of questioning, planning, implementing, concluding and reporting improved students' convergent thinking in scientific inquiry (Yang et al., 2016). Furthermore, the documentation of the thinking process approach prompts the students to not only visualize their arguments, making their decision-making process easier and engaging deeper into the learning challenge, but they also avoid group thinking and freeloading (Kilic-Bebek et al., 2023). Recent methods attempted to offer continuous guidance in training innovative thinking through artificial intelligence (AI). Thereby the human brain is the main actor (Habib et al., 2024), while AI is utilized as a boundary condition, as a coach, or as a challenger, requesting the students to find new approaches to problem-solving, rather than providing a solution (Marrone et al., 2022; Medeiros et al., 2023).

Problem In Teaching DT and CT Independently but Simultaneously.

Several studies have attempted to develop a holistic approach towards teaching DT and CT skills. The instructional framework of questioning, planning, implementing, concluding and reporting improved students' convergent thinking in scientific inquiry (Yang et al., 2016). The documentation approach prompted the students to express everything that happened in their thinking process and to document it. By presenting their arguments, and explaining their behaviour, their decision-making process became more understandable and more engaging (Kilic-Bebek et al., 2023). Similarly, many other studies have attempted to define proper teaching methods for DT and CT skills (González-Salamanca et al., 2020). However, until the current moment, there is no teaching method that can simultaneously teach DT and CT skills, while also offering them the necessary attention that each of them requires independently (Sak & Oz, 2010).

Cognitive Training

The current study suggests that cognitive training may serve as an effective method for simultaneous yet independently developing DT and CT skills. Cognitive training is a teaching method that makes the underlying cognitive processes involved in learning explicit (Ruiz-Martín & Bybee, 2022). This method enables the learners to gain a clearer understanding of the thinking skills of DT and CT as they emerge when one attempts to innovate. Such explicit practice enhances learners' understanding of the metacognitive processes occurring in the brain during skill development (Persky & Robinson, 2017). By making these processes explicit, students may become better equipped to untangle and understand the cognitive steps they follow when thinking innovatively about a solution to a given problem (González-Salamanca et al., 2020).

Similar cognitive training has revealed positive results in the performance of creativity tasks (Chapman et al., 2017). Specifically, even basic cognitive training enhanced the students' creative thinking (Braßler & Schultze, 2021), by making the development of the creative process, as described in the DD model, explicit. Additionally, cognitive training appeared to offer guidance to the students throughout the creative process, by clarifying the learning path they followed (Kim et al., 2023). Given the strong connection between creativity and innovative thinking (Avcı & Durak, 2023; Rios et al., 2020), it is reasonable to assume that similar benefits would be obtained when offering cognitive training for innovative thinking skills.

Cognitive training enhances the learner's ability to develop new ideas by explaining to them the executive functions they engage in when innovating (Liang et al., 2024). Executive functions refer to an individual's capacity to regulate their thoughts and behaviour. Through cognitive training, learners are better equipped to understand the mental and cognitive patterns activated in their brains when engaging in activities. This heightened awareness of their thought processes enables them to exert greater control over their thoughts and actions through executive function control (Sandford, 2003). Similar positive outcomes were obtained for older people, where cognitive training significantly improved their innovation processes, by deepening their understanding of the cognitive processes involved (Chapman et al., 2017).

In the case of innovative thinking skills cognitive training would involve making explicit the DT and CT processes that underline innovative thinking (Kim et al., 2023; Sun et al., 2020). Understanding the connection and interaction between the processes could teach the students of processes they follow when engaging in innovative thinking (Braßler & Schultze, 2021). This approach allows the learners to grasp the connection between the sub-skills of DT and CT. Furthermore, cognitive training could provide the learners with a conceptual map of the thinking processes involved in innovation (Kim et al., 2023). Such knowledge could support them to self-direct their learning into improving their innovative thinking skills.

Research Question

Hence, it is hypothesized that clearly explaining the subprocesses of DT and CT and the way they are interconnected increases the innovative thinking skills, regardless of the original DT or CT preferences of the students (West et al., 2012). To reach this goal the DT and CT processes that underline innovative thinking would be made explicit (Kim et al., 2023; Sun et al., 2020). Understanding the connection and interaction between the processes could teach the students what processes they follow when thinking about an innovation (De Vries & Lubart, 2017; Sun et al., 2020). This knowledge could support them to self-direct their learning into improving their innovative thinking skills, by focusing where needed. Hence, the hypothesis is that cognitive training on innovative thinking skills can improve the DT and CT skills development of higher education students. This paper is dedicated to the research question: *What effect does cognitive training have on divergent and convergent thinking skills of higher education students?*

Methodology

Research Design

The study aimed to determine whether cognitive training on innovative thinking skills could enhance students' DT and CT skills development. A quasi-experimental design was used, with an experimental group that received the cognitive training and a control group that engaged in solving Sudoku puzzles as a neutral or comparison activity. The quasi-experimental approach was preferred due to the practical ease of the approach, while still maintaining the experimental advantages of hypothesis validation and estimating the cause-effect connection (Ovbiagbonhia et al., 2020; Ovbiagbonhia et al., 2023; West et al., 2012). As a similar study has not been conducted yet in realistic educational settings, the current study serves as a pilot to allow for further investigation in an extended version in the future (In, 2017).

The hypothesis that is tested is that cognitive training on innovative thinking (the independent variable) will positively affect DT and CT skills (the dependent variables). The effect of cognitive training on DT and CT skills was assessed through two conditions, whereby the experimental condition followed the cognitive training. In contrast, the control condition was engaged in sudoku puzzle solving.

The study used a quantitative approach to analyse the data, comparing between- and within-subjects. All data collected either had originally a numerical form or were consequently transformed into numerical values. This method allowed for quantitative data aggregation and predictions (McFadden, 2021), suitable for a pilot study (In, 2017).

Respondents

In total, 57 participants between the ages of 19 and 64 (Mage = 27.61, SD = 8.04) took part in the experiment. 28 Participants (49%) were assigned to the control condition and 29 (51%) to the experimental. Their nationalities varied between Dutch (32%, N = 18), other European (35%, N = 20) and non-European (33%, N = 19). Most of the participants reported to be male (56%, N = 32), while 40% reported to be female (N = 23), 2% gender neutral (N = 1) and 2% preferred not to indicate (N = 1).

The participants of the experiment were Bachelor (N = 13, 22%) and Master students (N = 24, 42%), as well as employees of the University of Twente (N = 20, 35%). The majority studied Business Information Technology, Business Administration and Industrial Engineering & Management (N = 11, 19%), Educational Science & Technology (N = 9, 16%), and Industrial Design Engineering and Industrial, Electrical Engineering and Mechanical Engineering (N = 7, 12%). Most were in the second year of their Master studies (N = 15, 26%) or third year of their Bachelor studies (N = 7, 12%), while some were in their pre- or first-year Masters ($N_{premaster}$ = 4, 7%, $N_{firstMSc}$ = 5, 9%). Their working experience was mostly spread between two and four years of experience (N_{2years} = 11, 19%, and N_{3year} = 11, 19%, N_{4years} = 6, 10%) and an important portion reported more than four years of working experience ($N_{>4year}$ = 13, 23%, respectively), while only a few had one or less years of working experience ($N_{<1year}$ = 7, 12%, $N_{<0years}$ = 9, 15%).

Information about the experiments was promoted via social media, promotion posters, the SONA system and personal contacts of the researcher for the University of Twente. Hence, the convenience sampling method was utilized. To ensure correct investigation of the effect of the training, random assignment was applied (Duddy, 2022). The predefined dates and times were offered when the workshops took place without information on the condition of each date and time. The decision regarding the condition offered was defined by the throw of a dice. The sessions of the two conditions occurred at different times, to ensure the lack of intervening variables through information on the other conditions. The conditions were filled parallelly, as participants were interchangeably assigned to each of the conditions.

Instrumentation

Learning Material

As the experiments were offered to students and professionals with different backgrounds and working experience, their prior knowledge could not be a priori taken into consideration, and the learning material could not be specialized to the needs of a specific target group. Hence, a generalized learning material was offered. The workshop material was designed based on a literature review regarding innovative thinking skills for beginners, and the input from the minor course Technologische Innovatie Processen (TIP) from Saxion University of Applied Sciences. The researcher of this study worked in close cooperation with a specialist from Saxion to design the most suitable cognitive training on innovative thinking skills. All learning materials can be found in Appendix A.

The learning material was offered only to the participants of the experimental condition. They followed a fifteen-minute training with theoretical concepts, information and examples of innovative thinking skills, as well as explanations and examples about DT and CT, and the processes followed to develop an innovative idea. Those elements of the theory appeared to be the most appropriate according to the cognitive training theory (Chapman et al., 2017; White, 1996). The workshop was offered by the researcher in English.

For the control condition, an unrelated activity was selected to ensure that no effect was introduced to the condition by any input sources (Mohr et al., 2009). More specifically, the participants of the control condition completed several Sudoku puzzles. The time of this activity was equal to the time of the workshop that the experimental condition followed. To ensure equal treatment towards the participants and the consequent benefits of participation in the experiment, a short version of the cognitive training workshop and a hand-out of the learning material were offered to the participants of the control condition after the completion of the whole experiment.

Measurement Instruments

To ensure proper measurement of the DT and CT skills a series of measurements were utilized to ensure higher validity (de Vink et al., 2021). More specifically, the original, baseline, levels of DT and CT of the participants (Wang et al., 2022) were measured through a pre-test based on creativity test batteries. Consequently, the practical DT and CT skills of the participants were measured through a tangible task. Therefore, a video was utilized to measure the DT activity, and a picture of the artefact outcome was utilized to evaluate the CT levels of the participants. A connected personal reflection was used to evaluate the task completed, allowing for a re-evaluation of the researcher’s interpretations of the video activities through self-reported measures (Kikas & Jõgi, 2015). Finally, a post-test, similar to the pre-test was utilized to assess the difference between baseline DT and CT skills, and the effect of the workshop on the experimental condition. Table 1 provides an overview of the tests. The next paragraphs present the measurements in detail.

Table 1

Measurement Instruments and Goals

Measurement Instrument	Measurement Goal
Pre-test	Baseline DT and CT
Task video	DT activity after training
Artefact picture	CT levels after training
Reflection	Own evaluation of DT and CT levels after training
Post-test	Effect of cognitive training on DT and CT

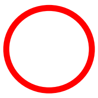
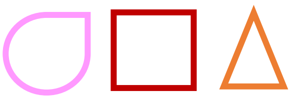
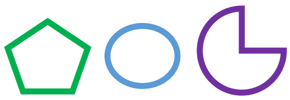
Pre- and Post-Tests

For the pre-and post-tests, items from two test batteries on creativity were utilized to ensure the evaluation of the two main categories deemed relevant for testing innovative thinking skills (Lévy-Garboua et al., 2024; Lubart, 2016). More specifically, items from the classic Torrance Test for Creative Thinking (TTCT) were utilized for testing basic verbal/literary skills of both DT and CT; and items from the Evaluation of Potential Creativity (EPoC) test were utilized to evaluate the graphic/visual skills.

For the pre-and post-tests, items from two test batteries on creativity were utilized to ensure the evaluation of the two main categories deemed relevant for testing innovative thinking skills (Lévy-Garboua et al., 2024; Lubart, 2016). More specifically, items from the classic Torrance Test for Creative Thinking (TTCT) were utilized for testing basic verbal/literary skills of both DT and CT; and items from the Evaluation of Potential Creativity (EPoC) test were utilized to evaluate the graphic/visual skills.

Table 2

Divergent Thinking Evaluation for the Pre- and Post-Tests

	Divergent Thinking	Convergent Thinking
Graphic/ Visual Pre-test	Make as many drawings as possible with the following shapes. 	Use as many of the following shapes as possible in a single drawing. 
Literary/ Verbal Pre-test	Find as many uses for a **pen** as possible.	Generate a complete story using the following characters. ***A little girl*** ***A hunter*** ***A king***
Graphic/ Visual Post-test	Make as many drawings as possible with the following shapes. 	Use as many of the following shapes as possible in a single drawing. 
Literary/ Verbal Post-test	Find as many uses for a **cardboard** as possible.	Generate a complete story using the following characters. ***An advocate*** ***A schoolteacher*** ***An interviewer***

Divergent Thinking.

In the pre-test for DT two measurements were utilized. As individuals might differ in their expression skills (Lubart et al., 2013), it was considered important to account for skills differentiation on learners' qualities level. The first measurement, related to verbal/ literary skills, required the generation of drawings including an O-like shape, within one minute (de Vink et al., 2021). The second measurement, related to graphic/ artistic skills, required the generation of as many as possible uses of a pen, within one minute (de Vink et al., 2021).

Similarly, for the post-test two DT-related measurements were utilized. The first measurement, related to graphic/ literary skills, required the generation of drawings including a triangle-like shape, within one minute (de Vink et al., 2021). The second measurement, related to verbal/ literary skills, required the generation of as many uses of a cardboard, within one minute (de Vink et al., 2021).

The shapes and the words created were evaluated against the three values of fluency, flexibility and originality. For fluency, the raw numbers of the shapes and words were counted (Lau & Cheung, 2010). For flexibility, the offered shapes and words (or sentences) were set into categories based on similarity. The categories were norm-based and defined by comparing afterwards the categories of the answers of all participants (Lau & Cheung, 2010). The norm-based assessment was selected due to its interactive and flexible nature, allowing the comparison between people, rather than against a standardized level, which would be impossible to define a priori, since this assessment has not occurred before (Freeman & Miller, 2001). The outcomes of flexibility were standardised by dividing the number of categories presented per participant's answer by the total of categories present. Finally, the outcomes of originality were standardised in percentages against the other categories. As originality is defined by the infrequency of the appearance of an idea in comparison to other ideas (Mayseless et al., 2015), the negative of the frequency of appearance of an idea was utilized. To reach this measure the amount of frequency of a response to a question was calculated and consequently subtracted from 100. The negative of this amount was the infrequency, hence the originality of an idea. It is important to repeat that this measure was self-designed based on theories and has not been used by other researchers. See Table 3 for an overview of the measurement levels for DT in the pre-and post-tests.

Table 3

Divergent Thinking Evaluation for the Pre- and Post-Tests

Category	Questions	Level
Divergent Thinking		
Fluency	How many drawings/ words are generated?	n
Flexibility	How many categories of drawings/ words are present?	n/N

Originality	How infrequently do the category of drawings/words appear (in comparison to the categories of drawings/ words of other participants)?	100%-n%/N

Convergent Thinking.

For the pre-test CT, two measurements were utilized. The first measurement, related to graphic/ literary skills, required the generation of an innovative drawing including as many of the offered shapes as possible, within one minute (Lubart et al., 2013). The second measurement, related to verbal/ literary skills, required the generation of a story including the offered characters, within one minute (Cheng et al., 2021).

Similarly, for the post-test two CT-related measurements were utilized. The first measurement, related to verbal/literary skills, required the generation of an innovative drawing including as many of the offered shapes as possible, within one minute (Lubart et al., 2013). The second measurement, related to verbal/ literary skills, required the generation of a story including the offered characters, within one minute (Cheng et al., 2021).

The drawings and the stories created were evaluated against the three values of correctness, innovativeness and completeness. For correctness, a score of one was given to the drawing and stories which utilized the elements to create a single drawing and story, while a score of zero was offered to the drawings and the stories that did not utilize all the elements in a single drawing, but rather in multiple. For completeness the number of correct shapes integrated was utilized (Cheng et al., 2021). The scoring ranged from zero to three, which was also the maximum number of objects offered in the assignment. Finally, for innovativeness, the infrequency of the offered drawings and stories was evaluated (de Vink et al., 2021). An answer was considered non-innovative if it was relatively frequent. Hence, the lowest the frequency of appearance, the more innovative the answer. Innovativeness was calculated by subtracting the percentage of the frequency of appearance of the category of an answer from 100. See Table 4 for an overview of the measurement calculations.

Table 4

Convergent Thinking Evaluation for the Pre- and Post-Tests

Category	Questions	Level
Divergent Thinking		
Correctness	Is the drawing/story what it was intended to be? Is it correct?	0-1

Completeness	Does the drawing/story fulfil all the criteria?	n
Innovativeness	How infrequently does this drawing/ story appear (in comparison to the drawings/ stories of other participants)?	100%-n%/N

Video of the Main Task

To evaluate the tangible practice of DT and CT skills the task of building a LEGO bridge was offered to the participants. This task has been utilized often as a learning tool for higher education students to practise basic engineering concepts and theories and has proven to be a valuable tool for evaluating background knowledge as well as soft skills among students (Sánchez-Cambronero et al., 2021). The specific parts of the task were developed by the researcher herself and were not based on previous literature on the topic of innovative thinking skills development. Throughout the test, the same core concepts of the theoretical framework were tested.

To carefully evaluate the behavioural development process of the participants while working on their artefact, video observation was utilized. This method is known to offer the advantage of observation, while also providing the possibilities for retrospective evaluation of various parameters, such as details of behaviour and the context or other situational parameters, that might originally not have been considered (Basil, 2011). Through the video observation, the DT skill levels were evaluated, given that only the process of development towards the artefact could be observed. The CT skills were better observable through the artefact outcome of the experiment, as is described in the next section.

Similar to the pre-and post-tests, the DT skills were evaluated against the three values of fluency, flexibility and originality also through the video. For fluency, the raw numbers of options tested were counted, following the same logic as in the pre-and post-tests (Lau & Cheung, 2010). For flexibility, the categories under which the different options fell were evaluated, again following the same logic as in the pre- and post-tests with a norm-based assessment evaluated after the completion of all tasks (Freeman & Miller, 2001; Lau & Cheung, 2010). Finally, for originality, the scores of the infrequency of appearance, hence originality, of the categories of each participant's answers were calculated by subtracting the frequency of appearance from the total of 100% of all categories. Table 5 offers an overview of all the measurements through the video.

Table 5

Divergent Thinking Evaluation of the Video

Category	Questions	Level
Divergent Thinking		
Fluency	How many bridge options were attempted?	n
Flexibility	How many categories of bridge options were attempted?	n/N
Originality	How infrequently were these bridge options attempted by other participants?	100%-n%/N

Artefact

The artefact of the task, the bridge, was utilized to interpret the CT skills since working towards an appropriate solution was easily evaluated through the artefact. Similar to the pre- and post-tests, the artefacts' CT skills were evaluated against the three values of correctness, innovativeness and completeness. For correctness, a dichotomous variable was tested, evaluating if the artefact was what it was intended to be, following the logic previously presented by Cheng et al. (2021) regarding correctness based on the pre-defined criteria. For an artefact to be correct all four elements of the main instruction needed to be fulfilled. More specifically, the artefact needed to be an overwater LEGO bridge for bikes, cars and people. Hence, the elements were *overwater*, *for bikes*, *cars* and *people.* If an artefact met all four elements, then it was considered a correct design for what it was intended to be, and hence, received a one. If the artefact missed any of the criteria, then a score of zero was assigned to it. For completeness, the number of criteria fulfilled were evaluated, namely *stable*, aesthetically pleasing, *height of minimum two big LEGO blocks*, *able to stand a weight of one kilo*, *breadth larger than an A5 paper* and *width less than an A3 paper*. The raw number of criteria fulfilled was the score of each artefact. This criterion-based approach was more suitable for the evaluation of CT skills, where predefined requirements need to be fulfilled to reach an appropriate solution (Sadler, 2005). Finally, for innovativeness, the infrequency of appearance of the category of an artefact was evaluated (de Vink et al., 2021) with a similar calculation as for the pre-post measured. For an overview of the measurements of the artefact, see Table 6.

Table 6

Convergent Thinking Evaluation of the Artefact

Category	Questions	Level
Convergent Thinking		

Correctness	Is the artefact correct? Is it really a bridge that humans, bikes and cars can use to cross over the water?	0-1
Completeness	How many of the criteria does the artefact fulfil? Stable Aesthetically pleasing Height: 2 big LEGO blocks Weight to stand: 1KG Breadth: Not touching the water (A5 paper) Width: Within the A3 paper	n/N
Innovativeness	How infrequently does this/ similar type of bridge appear (in comparison to the bridges of other participants)?	100%-n%/N

Reflection

Finally, to take into consideration the thinking process of the participants while innovating, a reflection was utilized after the completion of the activity. The utilization of video observation along with personal reflection has proven to provide a complete overview of behavioural observation of learners (Merriam et al., 2018). Hence, the reflection was utilized to offer a complete overview of the DT and CT skills development. Similar to the task, the reflection was not based on previously existing tools but was rather developed for the needs of the current study.

Divergent Thinking.

The three values of fluency, flexibility and originality were tested for DT through the reflection as well. For fluency, the raw numbers of possible options were evaluated, following again the rationale of Lau and Cheung (2010). For flexibility, the participants were requested to identify under how many different construction categories their findings could be considered to belong. This norm-based assessment allowed the participants to define their DT skills (Freeman & Miller, 2001). Finally, for originality, the participants were requested to evaluate the originality of their selected solutions against the other solutions that they had considered. A positive percentage of originality was offered as a response.

Convergent Thinking.

For CT the measures of completeness and innovativeness were evaluated, as through the previous methods. For completeness, the self-reported scores of the number of criteria fulfilled according to their creators per artefact were collected, criterion-based. Similarly, for innovativeness, a criterion-based approach was utilized, whereby the participants were shown pictures of previously created artefacts and were asked to give a percentage of innovativeness to their bridge in comparison to the other ones, whereby the innovativeness was given a score between one and 10, with one indicating the lowest innovativeness. These criterion-based assessments allowed for comparison based on some pre-defined standards (Sadler, 2005), which were more relevant for the CT skills that require a single suitable solution. It is important to note that after careful consideration, and feedback from the pilot studies, the measurement of correctness was eliminated from the reflection. There were no participants who reported to not have designed a bridge for the given purposes. Hence, the element of correctness was dismissed. Table 7 provides an overview of the measurement calculations of DT & CT for reflection. Table 8 provides an overview of all the measurements per test.

Table 7

Divergent and Convergent Thinking Questions for Reflection

Category	Questions	Level
Divergent Thinking		
Fluency	How many bridge structure options did you think of for your bridge?	1-10
Flexibility	Comparing those options among them, how different do you think they were from each other?	0-100%
Originality	How original do you think your solution is in comparison to other options you thought of?	0-100%
Convergent Thinking		
Correctness	-	-
Completeness	How many criteria do you think that your bridge fulfilled?	0-6
Innovativeness	How original do you think your solution is in comparison to other options?	1-10

Table 8

Overview of all Measurement Levels

	Test Type	
Category	Explanation	Level
	Pre- and Post-Test	

Divergent Thinking	Fluency	How many drawings/ words are generated?	n
	Flexibility	How many categories of drawings/ words are present?	n/N
	Originality	How infrequently do the category of drawings/words appear (in comparison to the categories of drawings/ words of other participants)?	0-100%
Convergent Thinking	Correctness	Is the drawing/story what it was intended to be/ correct?	0-1
	Completeness	Does the drawing/story fulfil all the criteria?	n/N
	Innovativeness	How infrequently does this drawing/ story appear (in comparison to the drawings/ stories of other participants)?	0-100%
		Video	
Divergent Thinking	Fluency	How many bridge options were attempted?	n
	Flexibility	How many categories of bridge options were attempted?	n/N
	Originality	How infrequently were these bridge options attempted by other participants?	0-100%
		Artefact	
Convergent Thinking	Correctness	Is the artefact correct? Is it really a bridge that humans, bikes and cars can use to cross over the water?	0-1
	Completeness	How many of the criteria does the artefact fulfil?	n/N
	Innovativeness	How infrequently does this/ similar type of bridge appear (in comparison to the bridges of other participants)?	0-100%
		Reflection	
Divergent Thinking	Fluency	How many bridge structure options did you think of for your bridge?	1-10
	Flexibility	Comparing those options among them, how different do you think they were from each other?	0-100%
	Originality	How original do you think your solution is in comparison to other options you thought of?	0-100%
Convergent Thinking	Correctness	-	-
	Completeness	How many criteria do you think that your bridge fulfilled?	0-6

Innovativeness	How original do you think your solution is in comparison to other options?	1-10

To ensure the quality of the tools, a pilot study was conducted (Aung et al., 2021). See Appendix B for an overview of the evaluation questions.

Procedure

Experiment Preparation

The study planning was accepted by the Ethics Committee of the University of Twente for June and July 2024. Since the online and paper-version creativity tests were found to yield similar and highly reliable results (Guo, 2019), the paper version was preferred to avoid any possible impact of technical implications or skills differences.

The participants took part in the study alone, in couples, and groups of a maximum of four people per session. Each session consisted of participants taking part in the same condition and experiencing only one condition. Participation in each condition occurred at different times. Hence the participants of each condition were not aware of the situation of the other condition. Regardless of the number of participants present in the room, each participant took part independently. Participants were randomly assigned to a session based on their availability and the availability of the condition.

Before the initiation of the experiments, the paper folders with the tasks to be completed were placed on the tables. Depending on the condition to which the participants belonged, a different folder was placed on their table, together with a pen. On the side, the materials for the task of building the LEGO bridge were prepared for the task that would take part later during the session. See Figure 2.

Figure 2

Experimental Materials Ready for use

Experiment Procedure

Each of the paper folders contained all the steps that the participants needed to follow to complete the experiment. They could follow the instructions on the papers. Parallelly, the researcher guided the participants through the experiment slides presented through a monitor screen. For every step, several presentation slides explained the step and the participants could ask questions. An overview of the process followed by the participants is represented in Table 9. The next paragraphs present the procedure in detail.

Table 9

Procedure of the Experiment as Experienced by the Participants, With Explanation and Time

Activity	Explanation of the Activity	Time in Minutes
Introduction	Introduction to the study, information about the informed consent, and demographic characteristics	10
Assignments I	Pre-test assignments examples and completion	5
Workshop or Sudoku	Cognitive Training for the experimental condition or Sudoku puzzles for the control condition	10
Task	Bridge building activity	20
Reflection	Reflection on the bridge quality and process	5
Assignments II	Post-test completion	5
Debriefing	Debriefing and questions	5

All guidance throughout the process was offered by the researcher. Firstly, information about the study was presented to the participants, who were consequently requested to offer their active informed consent in their participation folder and to complete the form with their demographic characteristics. On the same paper, a participant number was given to ensure confidentiality. They were asked to keep this number for 10 days in case they wished to withdraw their data from the study.

Afterwards, all the participants were introduced to the post-test. Before each assignment, an example was offered to ensure that the participants understood the actions they could take to complete the tasks. For each of the four assignments, the participants were given one minute to complete, while the researcher kept the time and informed the participants when the time was over. The complete process lasted approximately 10 minutes.

After the pre-test, the two conditions followed different processes. The participants in the experimental condition were introduced by the researcher to the cognitive training about innovative thinking skills for 10 minutes. The participants of the control condition were filling in one or more Sudoku puzzles also for 10 minutes.

Thereafter, both groups followed the same procedure again. Both conditions were introduced to the main task of the experiment. Thereby the participants had to individually create a LEGO bridge. The instructions and requirements for the task were presented by the researcher and remained visible on the screen throughout the whole duration of the task. Once the task was clear to all the participants, the recording and the time for completion started. When the time elapsed or when the participant indicated to have completed the task to their satisfaction, the timer and the video recording were stopped. For the evaluation of the artefact, a picture was taken of the LEGO bridge before its distraction.

Consequently, the participants of both conditions were asked to answer the questions in the post-test, following the same procedure as in the pre-test, but without the prior examples. The researcher kept the time, which in total lasted for approximately five minutes. Finally, at the end of the study, a debriefing about the experiment was offered by the researcher, whereby the two conditions were explained, and possible questions were answered. Additionally, for the control condition, a short version of the cognitive training on innovative thinking skills was offered and a hand-out of the training was provided to replace the lack of the training.

After completing all the tasks, the participants were asked to give their fill-in forms to the researcher. Finally, the participants were reminded to keep the participant number, in case they would wish to withdraw from the study in the future.

All data were immediately scanned and archived on the laptop of the researcher within a password-kept folder, and consequently uploaded to the University of Twente's secured Group Folder. The paper documents were stored at the University of Twente's store space.

Data Analysis

To be able to run the analysis comparing the different elements all data needed to be numerical. Hence, all scores from pre-and post-test, video observation, artefact and reflection were transformed into decimal numbers, based on their contributing percentage.

To analyse the data, the statistical program R Studio, R version 4.4.1, with the packages *rstatix*, *effectsize*, coin, *lessR* and survival were utilized. Before the main analysis of the data, the parametric assumptions were tested. As the parametric assumptions of normality and additivity largely, and homogeneity partially were violated, non-parametric tests were considered suitable for the analyses.

To ensure inter-rater reliability, 10% of the data was evaluated by a second coder. The results determined the coding reliable, as similar results were obtained with a κ of 0.8. Furthermore, the reliability of the whole test was evaluated with a Cronbach's alpha analysis (Taber, 2017; Collins, 2007). The alpha at .65 level indicates moderate internal consistency, which was mostly lowered by the CT-related measures at a level of .01, while the DT-related measures scored at .79. The predictive validity of the experiment was tested through a pilot study with two participants, one per condition, before the experiments.

To assess the effect of cognitive training on innovative thinking skills the pre-and post-test were evaluated. The main analysis consisted of two parts. The first part comprised a between-groups comparison, where the two groups experimental and control, were compared through Mann-Whitney U tests. The second main analysis compared the pre-and post-test measures of the two conditions. Wilcoxon signed rank test was utilized to those ends.

Results

Descriptive Overview of Main Variables

The descriptive statistics analysis that was conducted on the main variables, provides no evidence for significant differences between the conditions for any of the measurements. On the within-subjects level, little differentiation is visible between the pre-and post-test results of the assignments. Table 10 provides an overview of the means and standard deviations per condition, task and measurement, while Table 11 delves deeper into the pre- and post-test differences between conditions distinguishing the literary and verbal tasks.

Table 10

Means and Standard Deviations per Condition and Task for DT and CT

	Divergent Thinking				Convergent Thinking			
	Experimental		Control		Experimental		Control	
	M	SD	M	SD	M	SD	M	SD
Pre-test	0.47	.13	0.40	.12	0.67	.09	0.66	.09
Video	0.20	.23	0.21	.15	-	-	-	-
Artefact	-	-	-	-	0.43	.17	0.40	.15
Reflection	0.35	.15	0.40	.19	0.79	.09	0.80	.10
Post-test	0.48	.13	0.39	.10	0.68	.07	0.67	.09

Table 11

Pre-Post Test Means Visual-Literary DT and CT

	Pre-test				Post-test			
	Experimental		Control		Experimental		Control	
	M	SD	M	SD	M	SD	M	SD
Visual DT	.36	.16	.26	.13	.39	.15	.28	.11
Literary DT	.57	.15	.53	.18	.56	.15	.51	.14
Visual CT	.63	.15	.63	.15	.68	.13	.64	.17
Literary CT	.71	.04	.69	.10	.68	.07	.70	.05

Between Groups Tests

A Mann-Whitney U test was performed to evaluate whether the two conditions differed in DT and CT scores on the bridge-building, artefact and reflection. The results indicated that there was no significant difference between experimental and control conditions, with a small effect for all four tasks, $z_{bridge\text{-}building}$ = .16, $p_{bridge\text{-}building}$ = .225, $z_{artefact}$ = .15, $p_{artifact}$ = .917, $z_{CTreflection}$ = .13, $p_{CTreflectio}$ = .326 and $z_{DTreflection}$ = .05, $p_{DTreflectio}$ = .743. Table 12 provides an overview of the Mann-Whitney U test results

Table 12

Mann-Whitney U Test Results

	W	P	R	CI	Interpretation
Video DT	482	.225	.16	.007, .42	small
Photo CT	399	.917	.15	.005, .29	small
Reflection DT	468	.326	.13	.005, .39	small
Reflection CT	427	.743	.05	.005, .33	small

Within Groups Tests

A Wilcoxon signed-rank test was performed to evaluate whether the pre-and post-test of the two conditions differed in their overall scores for the assignments. The results indicated a small effect difference for both DT, ($z = .07$, $p = .628$), and CT, ($z = .29$, $p = .026$). Table 13 provides an overview of all the obtained Wilcoxon signed-rank test results, and Table 14 provides an overview of the medians

Table 13

Wilcoxon Signed Rank Test – Summed Data

	V	P	R	CI	Interpretation
DT pre-post	765	.628	.07	.005, .32	small
CT pre-post	545	.026	.29	.05, .55	small

Table 14

Median per Test

	Median pre-test	Median post-test
Visual DT	.32	.33
Literary DT	.54	.49
Visual CT	.71	.74
Literary CT	.73	.71

Third Variable Tests

The final analyses conducted were the correlational analyses intending to investigate whether any third variables from the demographic characteristics might influence the main study results. The analyses were separated into pre-and post-tests and in analysis of the task, shows no consistent impact of intervening variables that might have influenced the results of the main analysis. Several demographic characteristics show statistical significance for some of the main variable values and there are some medium and strong correlations. However, the results are not consistent along the variables and among CT or DT measurements, indicating no third variable impact that should be considered as an intervention to the main analysis results. Finally, the strongest correlations are between the same tests. For instance, pre-test DT correlates strongly with post-test DT, which is an expected result, given that they are the same measurement repeated. Tables 15 and 16 provide an overview of the correlational analyses.

Table 15

Correlational Analysis for Third Variable – Pre-and Post-test

	1	2	3	4	5	6	7	8	9	10
1. DT Pre-test										
2. CT Pre-test	-.25									
3. DT Post-test	.78**	-.13								
4. CT Post-test	-.20	.44**	-.20							
5. Employment Status	-.98	-.02	-.13	.10						
6. Year of Study	.01	.05	-.13	.16**	.55**					
7. Work Experience	.10	-.45**	.04	-.23	.01	.02				
8. Gender	.29*	-.13	.27*	-.15	.08	.07	.13			

9. Age	-.14	-.02	-.22	.02**	.37**	.46**	.40**	.19		
10. Nationality	-.16	.10	-.17	-.13	.02	.02	-.17	-.15	-.14	

Note: * *p < .05* ** *p ≤.01*

Table 16

Correlational Analysis for Third Variable - Task

	1	2	3	4	5	6	7	8	9	10
1. DT Video										
2. CT Artefact	.19									
3. DT Reflection	.11	-.03								
4. CT Reflection	.06	.13	.19							
5. Employment Status	-.09	-.07	-.02	-.02						
6. Year of Study	-.36**	.03	-.25	-.13	.55**					
7. Work Experience	.09	.03	.21	.03	.01	.02				
8. Gender	.13	.22	-.14	-.09	.08	.07	.13			
9. Age	-.11	-.12	-.05	-.10	.37*	.46*	.40*	.19		
10. Nationality	-.09	-.29*	-.01	-.28*	.02	.02	-.17	-.15	-.14	

Note: * *p < .05* ** *p ≤.01*

Discussion

The purpose of the current study was to evaluate the effect that cognitive training has on the innovative thinking skills of higher education students. To test the hypothesis that cognitive training has a positive impact on the subprocesses of DT and CT of innovative thinking skills, a quasi-experimental study was conducted. Participants of this experiment were students and employees of the University of Twente. They were randomly split into two conditions, with the only difference being the addition of the cognitive training for the experimental condition. The data were analysed both within- and between-subjects to evaluate the impact of the cognitive training on the participants. The following paragraphs provide an overview of the main outcomes, providing support for the answer to the research question, several secondary outcomes, investigating deeper some noteworthy observations, and finally provide some limitations, recommendations and practical implications that arise from the findings of the current study.

Main Outcomes

The results of the study showed no statistically significant differentiation between the two moments of testing, pre-and post-test. This is an expected outcome given that the test of the two moments were based on the same test batteries (Lévy-Garboua et al., 2024; Lubart, 2016). If anything, this proves that the test was valid, as it provides similar results between the two testing moments.

Further, no statistically significant differentiation was identified between the pre-and post-test for the participants of the two conditions. This indicates that the cognitive training had little effect, as the participants of the experimental condition showed similar results in the pre-and post-tests, as did the participants of the control condition.

The outcomes of the task analyses provide similar results to the pre-and post-tests. No statistically significant results with large effects were obtained among the different parts of the task. These results verify the previously obtained results of the pre-and post-test that the intervention of cognitive training does not have an impact on innovative thinking skills.

Those unexpected outcomes contradict the original hypothesis that was developed based on literature (Chapman et al., 2017; Kim et al., 2023; Ruiz-Martín & Bybee, 2022; Sun et al., 2020; West et al., 2012; Zhou, 2018). According to Braßler and Schultze (2021) and Ruiz-Martín and Bybee (2022), merely making explicit the cognitive processes of the learners when innovating should provide the students with the necessary tools to improve their innovative thinking process.

Hypothesizing on the reasons behind this differentiation, one could assume that the obtained results might be the outcome of contradicting parameters. For instance, Persky and Robinson (2017) propose that the cognitive steps one takes when learning new skills need to be made explicit in detail to be understood. It is possible that the provided training was not detailed enough. The fact that the training session was short and compact, might have forced the participants to process a large amount of information in a short time, with the result of lowered comprehension. A more longitudinal study would allow the students to understand the material more deeply and to evaluate their learning after a period. This is a common approach in teaching and learning, based on the notion that repetition of information is required before skilful application (Ranganathan et al., 2020).

Additionally, it is possible that the information provided was not understood given the short time provided for comprehension and application during the experiment. This suggestion is also in line with a recommendation for studying innovative thinking skills development over a longer period and assessing learning in the students' natural environment.

In such conditions, the normal learning process of the learners is promoted, and their learning is not only tested in isolated conditions but as it would occur (Delanoeije & Verbruggen, 2020).

Furthermore, it can be considered that innovative thinking skills might not have been the only predictor of innovative achievement. Previous studies indicate that general prior knowledge on a topic can influence an individual's performance on new learning material (Runco & Acar, 2012). In the case of the current tasks, the quality of the materials, the participant's previous knowledge about bridges and their previous experience with prototyping could have been parameters influencing their innovativeness. Randomised control trials could have offered more insightful results regarding the impact of cognitive training on the improvement of DT and CT skills (Mohr et al., 2009). According to this approach, random selection and evaluation of each element between methods provides stronger support for the generalizability of the study's outcomes. As such multiple tests with diverging parameters could be conducted to evaluate with a combination of DT or CT preference, prior knowledge level and environmental parameters would be more beneficial for high performance in innovation.

Furthermore, bridge building, as a common learning task for engineering studies, is usually practised as a cooperative task. This notion is in accordance with the current need for interdisciplinary collaboration between specialists in the fields of design and engineering, where innovation is often a basic requirement (Fernandez-Cosials & Gonzalo Jimenez, 2016; Sun et al., 2020). Communication between team members on the same task can increase the innovativeness and effectiveness of the innovation outcomes (White, 1996). Hence, a more collaborative task might have been more relevant to the needs of the study of innovative thinking. Thirdly, previous studies in the field of instructional design have proven that a single iteration of the main task of bridge construction, might not have been enough. Further iterations, prior and consequent to the cognitive training might have provided more insightful results (Sánchez-Cambronero et al., 2021).

Secondary Outcomes

Next to the main analyses regarding the original hypothesis, several additional points of attention arise from the outcomes of the current study. Firstly, it is noticeable that the participants scored overall higher in the CT skills than the DT skills, regardless of their condition and test moment, pre- or post-test. It could be speculated that those outcomes are a result of the educational level of the participants of the current study. More specifically, all participants were either higher education students or scholars of higher education. Some studies provide evidence that educational level could lead to higher goal-setting effectiveness, connected to CT (Ivancevich & McMahon, 1977). However, these findings should be treated with caution for several reasons.

Firstly, as already indicated in the theoretical framework of the current study, there is no clear agreement among scholars regarding the nature and connection of the two processes (Duval et al., 2022; Gangi, 2018; de Vink et al., 2021). Some scientists consider DT and CT inherently oppositional to one another, whereby for one to be activated, the other needs to be inhibited (Lévy-Garboua et al., 2024). Other scholars, however, consider that there is little differentiation between DT and CT skills. For instance, Goldschmidt (2016) suggests that brain areas associated with DT, namely frontal lobes, are simultaneously activated as the areas related to CT, namely parietal lobes (Mayseless et al., 2015). This is also in line with the dual model of creativity (Martindale, 1999), according to which creativity requires both the generation of novel and remote associations, connected to DT; and the simultaneous determination of suitable connections, related to CT. This association could lead to the perception of them as a single process of innovative thinking (Allen & Thomas, 2020). Furthermore, according to other studies, DT could be considered a moderator of CT, especially in the field of scientific inquiry (Zhu et al., 2019). These results underline the need for a deeper understanding of CT.

Finally, the high scores on CT in the current study are questionable due to the low Cronbach's alpha obtained by the relevant analysis conducted on all the CT measurements. These scores not only indicate low internal consistency of the measures of CT but also lower the overall consistency of the study (Tavakol & Dennick, 2011). These results stress once more the need for more accurate CT measurements.

However, taking those results as correct, one could not fail to notice that the participants of all conditions scored consistently higher on CT for the literary tasks. The higher scores on both the literary tasks and the CT skills might be related to the higher educational level of the participants. More specifically, Ivancevich and McMahon (1977) have already connected CT to higher goal effectiveness. In other words, highly educated people tend to be more goal-oriented and persistent in reaching their goals and score higher on literary tasks (Lozano-Blasco et al., 2022).

Limitations & Recommendations

Furthermore, it is important to consider several limitations of the current study. Taking those limitations into account improved future versions of the study can be reached.

Firstly, the difference between innovative thinking and creativity is still unclear in the literature. For the needs of the current study, the two concepts were considered the same, and tools from creativity research were utilized for the study of innovative thinking skills, namely the pre-and post-tests. However as not all academics agree on this approach (Peñalver et al., 2018), it can be assumed that several of the methods used in the current study might need refinement. A deeper investigation into the difference between innovative thinking and creativity could propose a clearer distinction between the two concepts or lead to an agreement that the two concepts can indeed be used interchangeably.

After the distinction between the two concepts, a refinement of the measurement tools might need to be conducted. The largest challenge of the current study occurred with the measure of originality. The measurement utilized was designed by the researcher, based on the theory of Mayseless et al. (2015) and was not previously evaluated by other researchers. Furthermore, to reach results fitting the descriptions of the theory required a multitude of complicated calculations. This makes the measurement prone to miscalculations and mistakes. Further refinement and verification of the measurement of originality by future studies would be required to ensure proper use.

Similar refinement and testing of the measurements would be required also for the task. All measurements related to the task, namely bridge building, artefact evaluation and reflection, were all designed by the researcher and were evaluated only through the pilot study. No previous iterations of the task have been conducted for the purpose of testing innovative thinking skills. Hence, further testing could assess the quality of the task as a measurement tool.

Furthermore, the current study utilized only numerical data. Non-numerical data could also provide some useful insights, which this study fails to investigate. For instance, qualitative evaluation of the task through open-ended questions reflections could provide accurate insight into the complete experience of the participants rather than only the evaluation of their performance (Roessner, 2000). This could also allow for reflection on their performance, which was proven to lead to improved academic results (Travers et al., 2014). Additionally, the combination of qualitative and quantitative data could provide a more holistic understanding of the experiment, and an extra validation of the measurements, as the qualitative data could validate the quantitative and the opposite (Kelle, 2008).

Finally, the current study was conducted only among a sample completely comprised of students and employees from the University of Twente. This approach might have limited the generalizability of the study considerably, given that it had low ecological validity

(Schmuckler, 2001). For a better understanding of the total population, a sample from a variety of institutions, as well as graduates of higher education not related to a university would be recommended (Jacobs & Narloch, 2001).

Practical Implications

Several of the outcomes of the current study can also be relevant for practical application in educational settings. More specifically, it is evident from the current study that cognitive training does not improve the innovative thinking skills of learners. However, educators should not be discouraged from using this method in their classrooms. As this is only one study, further finetuning of the method and validation of the current measurements would be required before concluding that cognitive training is an inadequate tool for improving innovative thinking skills.

Furthermore, the current study did not use an adaptive method. The students' level of DT and CT skills were tested, and the general cognitive training was given to all of them equally. Given the large differences between DT-and CT-prone learners, a training approach adapted to their needs might have reached different results (Kikas & Jõgi, 2015). Hence, one training could be offered to DT-prone students and a different training to CT-prone students to help them reach equally high levels of DT and CT skills.

Finally, it is important to consider some indirect results of the current study. On average, the participants in the current study appeared to score higher on CT rather than DT. This finding proposes that the participants focus more on completing the assignment task, rather than brainstorming about novel approaches. Similar results arise from other studies. Bingölbali and Bingölbali (2022) propose that DT is activated with abstract and unspecific tasks, while CT is activated with tasks requiring a single solution. de Vink et al. (2021) propose that CT is prominent in single-solution problems. Finally, other studies indicate that CT skills are more intuitive rather than DT skills, which can be learned (Xia et al., 2021). Those results could be translated as an intuitive preference for solution-oriented CT among the learners. This notion could have important implications for the educational system in general since it might suggest that for students to focus on innovating a less task-oriented educational system is required.

Conclusions

Overall, it can be concluded that cognitive training on innovative thinking skills does not appear to be the most effective method for improving innovative thinking skills of higher education learners. Neither DT nor CT skills seemed to have any statistically significant difference after the training in either of the experiment conditions. Contradicting the original hypothesis and the previous literature, this outcome indicates a low impact of cognitive training on the innovative thinking skills of higher education students. However, educators should not be discouraged from using this tool. It is possible that application under different circumstances or adjustment of the learning tools and conditions could provide more positive results.

Contrary to the negative results for the hypothesis, some secondary outcomes of the current study offer some noteworthy insights regarding the way education is offered. More specifically, the participants of the research scored repeatedly higher in CT rather than DT skills. The strong focus on the CT skills of the learners might be an inhibitor of the innovative thinking skills of the learners. However, such statements could not be made based on a single study. Further research is required. Investigating the development of innovative thinking skills in real educational settings for specified learners, in longitudinal studies could yield more reliable results. Using the current study as a pilot; and adjusting the practical limitations regarding creativity, CT evaluation and originality measurements could provide a solid basis for testing this hypothesis in future research.

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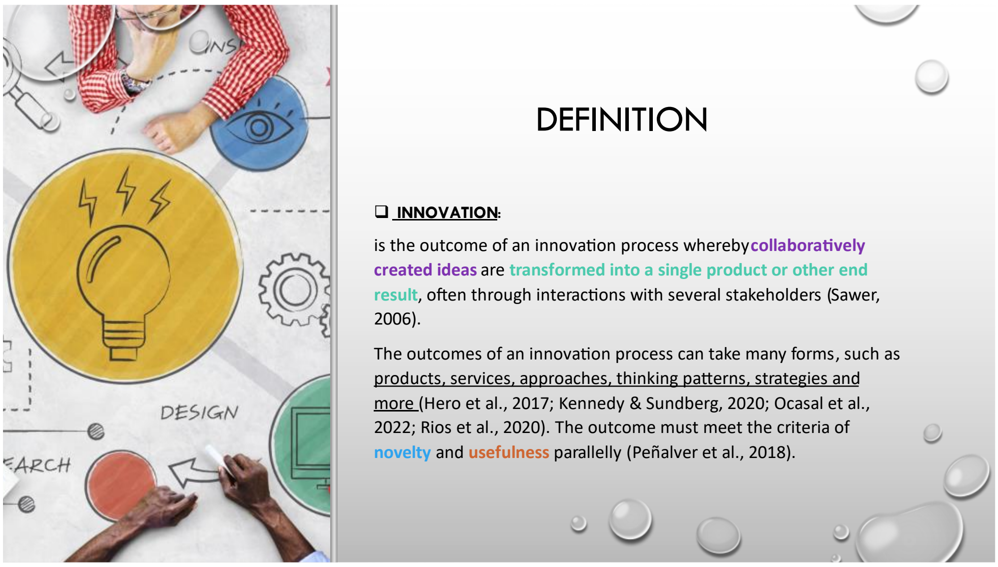
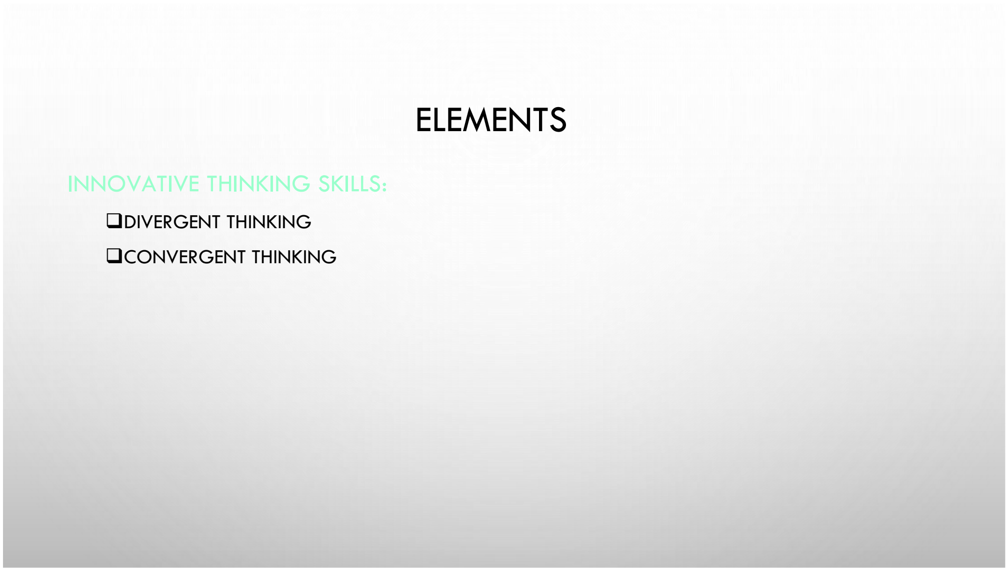
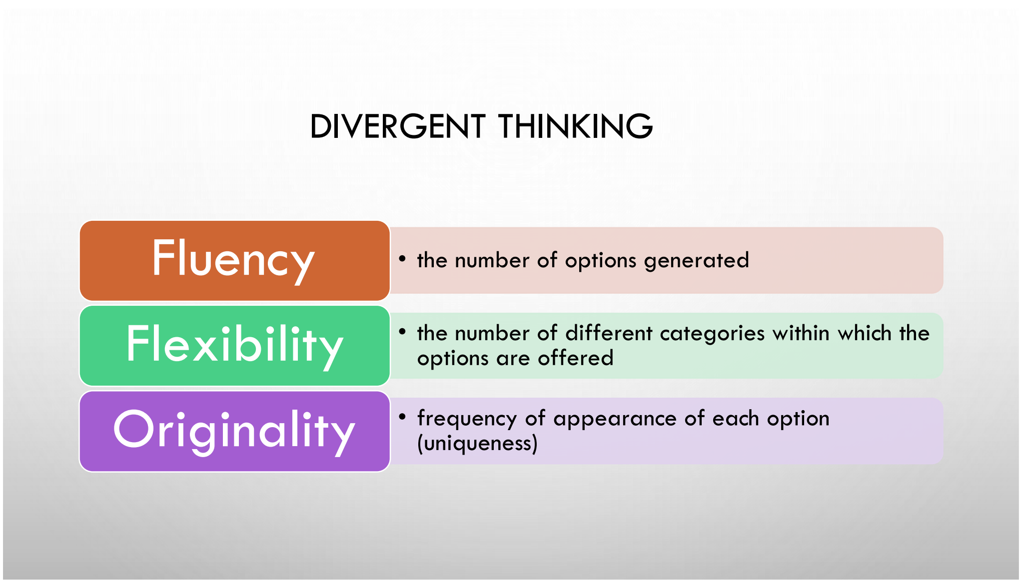
Appendices

Appendix A – Learning Material







CONVERGENT THINKING

Correctness	Innovativeness	Completeness
• the number of correct/relevant solutions generated	• frequency of appearance of each solution (uniqueness)	• the utilization of all offered elements in the final solution

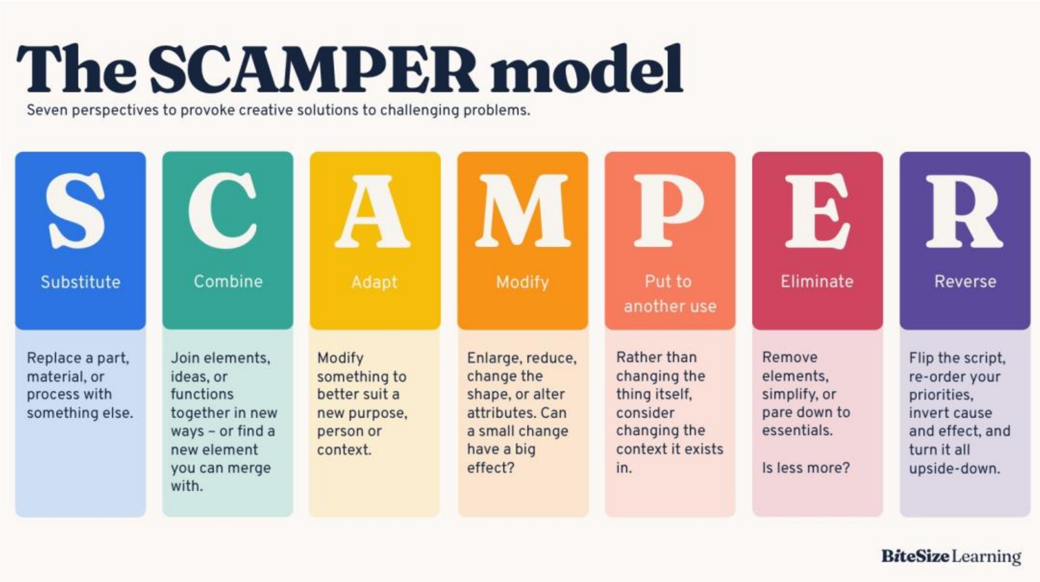
TECHNIQUES FOR DIVERGENT THINKING IMPROVEMENT

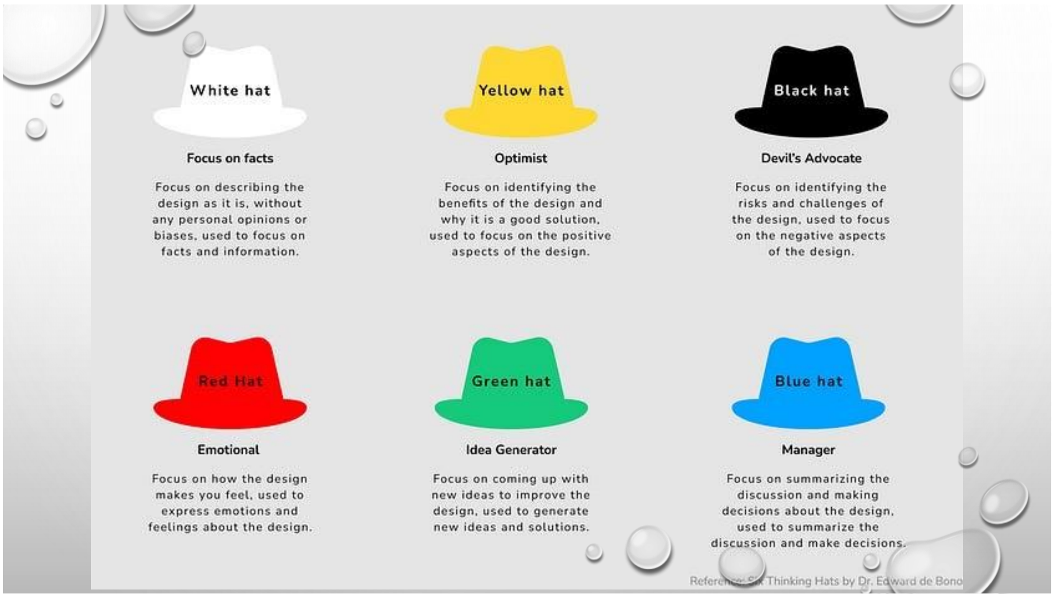
SCAMPER

- ❑SUBSTITUTE, COMBINE, ADAPT, MODIFY, PUT TO ANOTHER USE, ELIMINAT E, AND REVERSE

6 THINKING HATS

- ❑FOCUS ON: FACTS/LOGIC, FEELINGS/EMOTIONS, PROCESSES/MANAGEMENT, BENEFITS/ OPTIMISM, CAUTION/FEARS, CREATIVITY/ALTERNATIVES





TECHNIQUES FOR CONVERGENT THINKING IMPROVEMENT

SWOT

- ❑STRENGTHS, WEAKNESSES, OPPORTUNITIES, THREATS

MULTIPLE CRITERIA DECISION ANALYSIS (MCDA)

- ❑SET SEVERAL CRITERIA, COLLECT OPTIONS FULLFILLING MOST OF THEM

MULTI CRITERIA DECISION ANALYSIS

Ratings 5 — 4 — 3 — 2 — 1

Criteria	Weight	Current Solution		Alternative 1		Alternative 2	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
	5	1	5	5	25	4	20
	2	3	6	3	6	5	10
Total Score			11		31		30

Appendix B – Pilot Evaluation Questions

Overall

How was your overall experience with the experiment?

What was the duration of the experiment?

Any other comments?

Assignments I & II

How was the 1' time limit? Was it enough/too much/ stressful?

Were the instructions for the assignments clear?

What did you think of the words and shapes? Were they clearly defined/ vague/ unexpected?

Workshop

How were the workshop instructions?

Was the information provided everything clear? Was it easy to follow?

Was the workshop too long/short?

Sudoku

How were the sudoku instructions?

Was the sudoku game easy to follow?

Task

How were the task instructions?

Was the general experience with the task?

Was the provided material enough?

Was the task too challenging/difficult/easy/engaging?

Were the criteria clear/too much/ too easy?

Reflection

How were the reflection instructions?

Were there any unclear questions?

How easy was it to indicate numbers for each question?

Is there anything that could support you more in answering the questions? *Keep in mind that open questions are not relevant to this experiment.*