# How constraints in problem solving affect creative reasoning?

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# CERTIFICATE

It is certified that the work contained in this thesis, titled 'How constraints in problem solving affect creative reasoning?' by A. Nishanth, has been carried out under my supervision and is not submitted elsewhere for a degree.

Date

Adviser: Prof. Priyanka Srivastava

To family, friends and
my professor **Priyanka Srivastava**

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# Abstract

Creativity is an interesting and exciting topic of research due its mysterious and complex nature. There is an ocean of literature present on the topic and our work is a drop in the ocean. To understand creativity, it is essential to understand the underlying cognitive strategies. Our thesis aims to understand how inducing different types of constraints impacts creative reasoning.

To address this question, we conducted a study that examines the role of constraints in well-defined problem-solving in ill-defined problem-solving. We chose variants of Raven's advanced progressive matrices(APM) for well-defined problem-solving and creative reasoning tasks (CRT) for ill-defined problem-solving. Using traditional APM, we created a novel version of APM with comparatively lesser constraints available to solve the puzzle, called creative APM($c$APM). The $c$APM task was designed to induce divergent thinking along with convergent thinking. It is assumed that the difference in constraints changes the nature of the problem space in solving APM and $c$APM and may differently affect the following creative reasoning task. We randomly assigned 50 participants to perform APM or $c$APM, followed by the CRT, in a fixed order. We observed a significant effect of constraints available to solve well-defined problems on ill-defined problem-solving. The current result showed higher CRT scores when CRT preceded $c$APM ($Median$ = 79.25) than APM ($Median$ = 53.00). The result suggests that the flexibility in constraints to solve a well-defined problem induces more divergent thinking alongside convergent thinking and facilitates creative thinking required in ill-defined problem-solving.

Following this study, we conducted another study to understand whether the constraints in the well-defined problem solving task impacts the ill-defined problem solving task of a different knowledge domain. The well-defined problem solving tasks remain same as the previous study. For the ill-defined problem solving task we have chosen creative reasoning tasks (CRT) which is of same knowledge domain and alternate uses task[46] of a different knowledge domain. We have collected a sample of 44 participants. We observed a significant effect of the variant of APM on CRT performance. Higher number of rules in the CRT was observed when it was preceded by $c$APM ($Median$ = 2) compared to the classic APM ($Median$ = 1). Further, we observed a higher CRT Relationship Score under $c$APM ($Median$ = 78.5) compared to the classic APM ($Median$ = 50.5) puzzle conditions. However, the variant of APM did not show a significant effect on AUT, fluency score($p = 0.8$ for independent t-test) and elaboration score ($p = 0.48$ for

Mann-Whitney U test). The current results fail to show domain general than specific nature of creative thinking, especially when it is induced varying the constraints of abstract reasoning.

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# *Chapter 1*

# Introduction

## 1.1 Background

Creativity is often seen as the essence of innovation, the key to resolving complex problems, and a crucial skill in many professions. Its relationship with problem-solving has been a subject of interest in psychological, educational, and organizational research. What kind of problems require creativity? For instance, a startup with a tight budget might need to innovate in product design or marketing strategies to compete with larger, better-funded competitors. Legal and ethical guidelines can inspire creative thinking to find solutions that meet both the desired outcomes and societal or regulatory requirements. For example, pharmaceutical companies must navigate complex regulatory constraints to develop safe and effective drugs, leading to inventive research and development processes.

When resources are limited, such as time, budget, or materials, individuals are often compelled to find efficient and creative solutions. These limitations on resources to predefined rules and frameworks can be collectively termed as constraints. In the above examples, constraints served as a catalyst for creative problem solving. But constraints can sometimes also have a negative impact on creativity, particularly when they are overly rigid or restrictive. Imagine a scenario in an elementary school where young students are given a creative writing assignment. They are tasked with writing a short story, but there are several constraints imposed on their creativity.

1. Strict Word Limit: The students are told that their stories must be exactly 300 words long, no more, no less.

2. Assigned Topic: They are all given the same topic to write about, leaving no room for personal interests or imaginative exploration.

3. Required Format: The stories must follow a specific format, with an introduction, three main paragraphs, and a conclusion. There's no room for experimentation with narrative structure.

4. Prescribed Vocabulary: A list of ”approved” words is provided, and students are told they can only use these words in their stories.

In this scenario, the constraints imposed on the students’ creative writing exercise are so rigid that they stifle their creative thinking and limit their ability to express themselves. The strict word limit and prescribed vocabulary limit the students’ ability to fully develop their ideas. They may find themselves omitting important details or struggling to convey their thoughts effectively within the constraints. Because they have little choice in the topic and format, students may not feel a sense of ownership or pride in their work. Creativity often thrives when individuals have the freedom to choose and shape their projects.

Historically, creativity was believed to be at its peak in unstructured environments, which presumably allow unbridled imagination. This view suggests that the fewer constraints imposed on a problem-solving process, the more creativity it engenders. However, more recent studies have started to challenge this idea, proposing that constraints can act as catalysts for creative thought [96]. They can provide a structure that stimulates creative thinking by pushing individuals to think beyond the obvious, question existing paradigms, and develop novel solutions. The studies in the field of organizational behavior and management have shown the practical implications of constraints on creativity and innovation. The right type of constraints can have a positive effect and some creative professionals enforce these constraints for their teams for a better innovation and creative performance [26]. However, they can also restrict creativity by imposing excessive stress or limiting the exploration of alternative solutions.

The relationship between constraints and creativity is likely complex and multidimensional, affected by the nature and severity of the constraints, the characteristics of the problem, and the cognitive and emotional responses of the individuals involved. One more interesting aspect of creativity is whether it is a domain-specific or domain-general phenomenon. Can a person be creative only in certain domain areas and normal in others? The researchers who support the domain-specific view of creativity chose the performance-based creativity assessment. These domains are usually narrowly defined such as mathematical problem or a drawing task [5, 6]. Whereas researchers who use self-report measures of creativity view it as domain-general where domains are loosely defined such as psychology and maths [65].

This thesis aims to build on these foundations by exploring how constraints impact creative reasoning in problem-solving. It will examine the role of constraints in shaping cognitive processes associated with creative reasoning, the conditions under which constraints might stimulate or hinder creativity, and the potential strategies for harnessing constraints to foster creativity in problem-solving. It also discusses whether creativity is more domain-specific or domain-general.

## 1.2 Motivation

The subject of creativity has consistently garnered significant attention in academic studies, primarily due to its widespread occurrence and intricate underlying processes. Creativity has always been a fascinating topic for me since childhood. As a young student, my understanding of creativity was whatever makes us stand out from the crowd and was unique, then it can be termed as a creative thought or work. Another popular notion of creativity which me and most of my peers believed was whoever was artists were creative, and the others were more logical or scientific. I also believed that creativity is a spontaneous inspiration like the ”Eureka” moment and it may or may not occur in an individual’s life. Later when I joined under professor Priyanka Srivastava, she suggested me to read the book ”Explaining Creativity” by Keith Sawyer. The most interesting thing I found in this book was there is an entire section dedicated to myths about creativity many of which I believed earlier. After reading some literature regarding creativity, I became very interested and wanted to work in this area. After learning about the underlying mechanisms and cognitive strategies of creativity, my question was can we take control of the underlying processes and necessary strategies to induce creative thinking into an individual?

I am therefore motivated to explore this fascinating dynamic through my thesis. I aim to delve into how constraints could foster creative reasoning, provide new insights into the cognitive processes involved in creative problem-solving, and devise strategies to intentionally use constraints as a tool for innovation.

## 1.3 Literature Review

### 1.3.1 Problem-Solving

Problem-solving is an essential skill that transcends cultural, societal, and professional boundaries. It is the driving force behind innovation, progress, and personal growth. Whether in our daily lives, in the workplace, or on a global scale, the ability to identify, analyze, and resolve problems is a fundamental aspect of human cognition. At its core, problem-solving is about finding solutions to challenges or obstacles that hinder progress. These challenges can range from simple, everyday dilemmas, such as fixing a leaking tap, to complex, multifaceted issues like climate change or global economic crises. The various types of problems can be distinguished using a concept called problem space. Problem spaces are abstract spaces that encompass all conceivable pathways and phases leading to a solution [55]. In addition, they also encompass the prescribed rules that individuals are required to employ in order to go from one stage to the subsequent one. Problem spaces can be classified on a continuum from well-defined to ill-defined based on the level of detail provided regarding the constraints of the problem [105]. Let’s explore different types of problem-spaces using some problems. Take the problem of Sudoku, here a fixed set of rules are already prescribed by the problem and there is no other way to interpret them. So the problem space here is deterministic as the rules cannot be subject to reinterpretation. These type of problems can be termed as well-defined problems.

**Well-defined problems**: These problems are characterised by a set of specific criteria, including fully described initial conditions, unambiguous objectives, a well-defined set of operators for altering conditions, and a finite number of potential solutions. One illustrative instance of a problem that has a clear definition is a sum problem, as it satisfies all the requisite criteria. Well-defined problems are classified as routine when they permit the application of efficient algorithms to provide solutions that are capable of fully meeting the initial requirements [24, 120]. Typically, problem-solving tasks that are well-defined entail the completion of a logical structure in accordance with explicit rules. In certain instances, these rules may need to be discovered, as is the case with pattern completion tasks [57] Eg: Raven Progressive Matrices test(RPM) [91].

On the other hand, there are certain problems which do not have a straightforward and definitive procedure to obtain solutions. Some examples include ”How to reduce traffic congestion in a city”, ”Where should I visit for my holiday trip?”. These problems don't have exact correct solutions. The problem spaces for these type of problems are not only abstract, but also indeterminate. These type of problems can be termed as ill-defined problems.

**Ill-defined problems**: These problems are characterised by a lack of unambiguous initial conditions, incompletely articulated goals, a multitude of uncertain solutions, and the absence of a defined set of operators or algorithms. Due to the inherent ambiguity of solutions to ill-defined problems it is not feasible to predict with certainty whether an algorithm would align with the initial requirements [20]. Due to this rationale, ill-defined problems cannot be solved by conventional methods. These particular problems are linked to the production of diverse novel solutions for the same problem scenario. One prominent characteristic commonly attributed to ill-defined problems is the production of unforeseen solutions that exhibit significant divergence from prior problem scenarios [113]. As this tends to be the prevailing circumstance, design problems are often viewed as prominent instances of ill-defined and non-routine problems.

### 1.3.2 Creativity

Creativity is a multifaceted construct that pervades various aspects of human functioning and society, often resulting in innovative ideas, unique solutions, and artistic expressions. In diverse contexts like education, business, and mental health, creativity has shown its significance. In education, fostering creativity is crucial for promoting problem-solving and critical thinking skills [22]. In the business world, creativity drives innovation and confers competitive advantage [3, 84]. The link between creativity and mental health is more complex, with research indicating both positive and negative correlations [63]. Creativity is commonly defined as the ability to generate ideas or solutions that are both novel and appropriate [109]. The understanding of creativity involves exploring its nature, measurement, influencing factors, and its role in different contexts. Historically, creativity was often perceived as an innate, divine gift. This perspective shifted significantly with Guilford's (1950) [45] seminal address to the American Psychological Association, advocating for the scientific study of creativity. He proposed that creativity was not merely an elusive talent but a mental function amenable to measurement and enhancement.

**Divergent Thinking**: Guilford's work led to the development of the divergent thinking paradigm, where creativity is measured based on fluency, flexibility, originality, and elaboration of thought. This paradigm was operationalized in the Torrance Tests of Creative Thinking (TTCT), one of the most widely used creativity tests [115]. Since then, divergent thinking has been a cornerstone in the study of creativity and problem-solving [23, 98]. Guilford (1950) [45] initially argued that creativity could be fostered by enhancing divergent thinking. Subsequent research supported this, finding divergent thinking to be a reliable indicator of creative potential [97]. Divergent thinking is underpinned by several cognitive processes. These include cognitive flexibility [31], associative thinking [75], and selective encoding and comparison [39]. Neuroscientific studies have found the right hemisphere and the prefrontal cortex to play a critical role in divergent thinking, pointing towards the complex interplay of cognitive and neurophysiological elements [15].

However, recent studies have nuanced this relationship, arguing that creativity is not solely a product of divergent thinking [88]. Other cognitive processes, such as convergent thinking and meta-cognitive skills, also contribute to creative output [85, 23].

**Convergent Thinking**: Convergent thinking was described as a cognitive process used in situations where a single correct answer exists, with an emphasis on speed, accuracy, and logic [45]. Since Guilford's foundational work, convergent thinking has been extensively studied in relation to intelligence, problem-solving, creativity, and decision-making. The correlation between convergent thinking and traditional measures of intelligence is well-documented. Cropley (2006) [23] suggested that most standard IQ tests primarily measure convergent thinking, as they necessitate arriving at a single correct answer. Convergent thinking is vital in problem-solving and decision-making contexts, especially those requiring analytical and logical reasoning [27]. Neuroscientific studies have implicated the left hemisphere of the brain in convergent thinking processes [16], underscoring its role in analytical and logical thinking. The relationship between convergent thinking and creativity is nuanced. While creativity has traditionally been associated with divergent thinking, recent research suggests that both divergent and convergent thinking are integral to the creative process [23, 59]. This perspective aligns with the dual pathway to creativity model [82], which proposes that creativity arises from both divergent thinking (generating novel ideas) and convergent thinking (refining and evaluating these ideas).

#### 1.3.2.1 Factors influencing Creativity

Understanding creativity also involves examining the factors that influence it. Individual cognitive abilities, personality traits, intrinsic motivation, and domain-specific knowledge are all recognized as significant contributors to creative potential [2, 108]. Creativity is not just an individual phenomenon. Environmental factors, including social, cultural, and organizational influences, also play a substantial role. Csikszentmihalyi's (1996) [25] systems model of creativity underlines this by emphasizing the interplay between the individual, domain, and field. Each factor influencing creativity can be referred as a 'constraint' that can either fuel or hinder the creative process. We will explore what constraints are and their effect on creativity in the following section.

### 1.3.3 Constraints

Constraints refer to limitations, boundaries, or restrictions that shape and influence cognitive processes and behaviors. These constraints can be internal or external factors that impact how individuals perceive, process, and respond to information and stimuli. Constraints play a pivotal role in shaping cognitive activities such as problem solving, decision making, memory retrieval, and creative thinking. In the following section, we will see how each constraint can effect creativity.

#### 1.3.3.1 Persons

Individuals exhibit a wide range of physical and psychological characteristics, encompassing various attributes such as personality, expertise, professional roles, race, gender, ethnicity, sexual orientation, physical ability, mental ability, age, health status, language, nationality, culture, religion, food preferences, childhood experiences, educational background, and hobbies. Psychologists consider these characteristics as variables or factors, but they can also be understood as constraints. Some of these constraints are related to concentration, such as interests, skills, and talents, while others are excluding, such as disabilities and health difficulties. The interaction of these internal constraints gives rise to intricate configurations that undergo changes over an individual's lifespan. Consequently, they serve as abundant sources of variability that can be harnessed to generate creative solutions. As an illustration, Lena Waithe, a screenwriter, producer, and actress, achieved a significant milestone in 2017 by becoming the inaugural Black American woman to receive a Primetime Emmy Award for Outstanding Writing for a Comedy Series. In her acceptance speech, she expressed gratitude for the various facets of her identity that contributed to her creative accomplishments. Notably, the award-winning episode was inspired by her personal journey of self-disclosure as a lesbian [119]. In the context of group creativity, it is seen that individuals' unique norms and assumptions amalgamate to create distinct "maps" that exhibit variability across different teams [50]. The presence of distinct and varied team personalities influences the pursuit of innovative results in directions that may not have been explored by others, hence enhancing the chances of discovering unconventional and inventive solutions [42]. Person constraints can arise from various origins.

**Personality**: When considered as constraints, personality factors direct an individual's creative energy towards specific creative fields while diverting it from others. For instance, this can be observed in the distinction between artistic and scientific pursuits [35]. Certain characteristics are particularly suitable for specific domains [7], influencing individuals' interests and career decisions by predisposing them towards activities that align with their specific personality traits and overall configuration [29, 87]. The primary concentrating constraint, when combined with additional factors such as aptitude and interests, may result in a stronger alignment with one pursuit over another. Furthermore, investigations conducted within the same domain reveal additional noteworthy distinctions. For instance, according to Benedek [13], there is evidence to suggest that jazz musicians exhibit a greater inclination towards openness to experience compared to classical musicians. Similarly, Fink and Woschnjak [36] found that modern dancers tend to display higher levels of openness to experience in comparison to ballet and jazz dancers.

**Cognitive Styles**: The cognitive styles of individuals have an impact on their cognitive processes, problem-solving abilities, and decision-making processes. Cognitive styles are distinguished from cognitive talents in that they pertain to unique and preferred methods of information processing that are employed instinctively, resembling a higher-level heuristic, rather than inherent capacities for processing [77]. According to research conducted by Zedelius and Schooler [126] in the field of behavioural studies, as well as studies conducted by Kounios and Beeman [68] in the field of neuroscience, it is suggested that problem-solvers have access to various cognitive processes. However, individuals tend to exhibit a predisposition towards a specific cognitive style, leading them to prefer and utilise one particular processing style over others. This preference is influenced by individual-specific tendency. The combination of intellectual talents, habits, and personality traits collectively serve as constraining factors that influence the formation and selection of a specific cognitive style. Furthermore, after a certain cognitive style has been developed, it facilitates the growth of certain intellectual capacities and personality characteristics, while potentially impeding the development of others [69]. Alongside other routes that are specific to individuals, cognitive styles have the potential to influence individuals' inclination towards particular creativity difficulties and professional trajectories. An illustration of divergent cognitive styles between journalists and poets can be observed, with journalists displaying a preference for well-structured tasks and poets exhibiting a preference for more open-ended problems [62].

**Talent**: Talent possesses a discernible capacity for selectivity and serves as a means of directing one's abilities, akin to the interconnected notion of interest. The possession of talent in a given area facilitates the acquisition of expertise and serves as a driving force in the pursuit of identifying and resolving creativity-related issues that are special to that domain. For instance, a research investigation on distinguished classical composers shown that their exceptional aptitude enabled them to acquire expertise in domain-specific components at a more accelerated pace compared to their less gifted peers [106]. While certain researchers have given greater importance to talent in the process of acquiring expertise [118], others argue that deliberate practise alone is enough to attain high levels of expertise across various domains [32, 33].

**Knowledge**: There are two distinct manners in which knowledge might impose limitations. Initially, it is imperative to possess a certain level of expertise in order to effectively address and resolve previously addressed issues. This entails comprehending the solutions that have been implemented and then identifying the remaining unresolved problems. Moreover, it is crucial to articulate these residual issues in a manner that fosters innovative and constructive outcomes [37]. The acquisition of knowledge encompasses both the ability to identify problems and the capacity to build domain-specific problems. Furthermore, the variety of knowledge offers novel perspectives and foundations from other domains. For instance, advancements in a particular field frequently involve the incorporation of novel aspects from other fields and the exploration of innovative and valuable combinations derived from these shared limitations. Put simply, the availability of a wide range of ideas and classifications supports the formation of adaptable frameworks of knowledge and more intricate concepts and classifications specific to a particular field [2]. Consequently, this can lead to the generation of more innovative combinations and results [114]. Furthermore, the evaluation of creativity is contingent upon the constraints imposed by pre-existing knowledge, as both the originality and utility criteria are assessed in reference to this knowledge.

#### 1.3.3.2 Physical Environment

The utilisation of physical locations and materials is a significant factor in the facilitation of the creative process [43]. These elements serve as essential tools for directing and limiting creative thinking, particularly within the framework of an established medium. As an illustration, Krzysztof Penderecki, a renowned Polish composer, articulated his endeavour to discover a distinct auditory experience while engrossed in the process of crafting a musical composition within the confines of a café. The auditory disturbance caused by the passage of a tramway served as an unexpected and fortuitous element that the composer included into his renowned musical piece, Threnody [72]. Penderecki also emphasised the significance of other physical limitations, specifically, the limited dimensions of the café table and the sole piece of paper at hand. These constraints led to the creation of novel and condensed notation symbols. According to Robinson [95], this technological advancement facilitated the process of organising musical tones, even in intricate compositions featuring numerous instruments and vocal components. As an illustrative instance, scarcity, which pertains to a cognitive perspective centred on the existence of limitations has been observed to foster creativity [103]. This has been evidenced, for instance, by the innovative solutions produced by homeless and subsistence consumers [54], as well as by the creative endeavours of incarcerated artists, which were recently exhibited at the Museum of Modern Art in New York City [38]. Within the realm of business, the presence of excess resources for entrepreneurs may lead to feelings of futility, complacency, and a decrease in exploratory innovation [121]. However, it is important to note that resource scarcity can also serve as a catalyst for frugal innovation [8, 89].

#### 1.3.3.3 Tasks

Creative activities, regardless of the level of competence, have an influence on many forms of creativity, ranging from small-scale to large-scale creative endeavours [64]. Additionally, these tasks span across several domains such as artistic, scientific, mathematical, and business creativity [66]. It is important to note that all creative tasks contain some form of constraint. In various domains, such as business, science, art, athletics, and leisure activities, creative pursuits are subject to various constraints. These constraints may arise from factors such as the market, organisation, team, individual, project, data, genre, medium, rules, and well-defined physical parameters [74].

The level of constraint in creative endeavours can vary, ranging from low to high, forming a continuum. Open-ended creative tasks, such as the composition of a poem, possess a lesser degree of constraint in comparison to closed-ended tasks, such as insight puzzles, which are characterised by the presence of a single correct solution. In the context of the classic nine-dot problem [18] or matchstick problems [102], there exists a singular solution that adheres to the specified constraints, allowing for the connection of the dots or arrangement of the matchsticks.

### 1.3.4 Significance of Investigating the Relationship

When we hear about the word ”constraints”, it is often associated with negative implications, suggesting a lack of choice and potentially removing the element of enjoyment. When constraints are imposed on speech, it might bring up the idea of censorship. The more constraints we are presented in a situation, we think of authoritarian rule, restriction, and obstacles that need to be surmounted, rather than presenting themselves as opportunities to embrace and welcome. In contrast, creativity is often linked to concepts of unlimited potential, vast horizons, unconventional thinking, and unrestricted possibilities. Therefore, it’s not unexpected that the relationship between constraints and creativity is seen as paradoxical. An increasing body of researchers have delved into this contradiction by investigating the overarching query of whether constraints support or hinder creativity [52, 94, 110]. Some discoveries indicate that specific constraints yield favorable outcomes [51, 52, 73, 94], while others indicate adverse consequences [86, 124].

A recent meta-analysis investigating the impact of constraints on creativity proposed that an inverse U-shaped correlation between different constraints and creativity could provide the most comprehensive explanation for the varied and sometimes contradictory results obtained so far [1]. How do constraints affect creativity in general? A study done by Tromp and colleagues states that no single main effect can adequately explain the nuanced part that limitations play in creativity. Instead, this role is influenced by the sort of constraint, how the individual responds to it, and how it interacts with other limitations that come from the individual, the creative activity at hand, and the surrounding environment. Depending on the particular person, work, and circumstance, the same constraint might provide a neutral, negative, or positive net consequence for creativity [117]. They have developed a model called Integrated Constraints in Creativity (IConIC) which explains how constraints impact creativity. According to Tromp [116], the IConIC model posits that creativity is significantly influenced by restrictions. Creativity does not arise spontaneously, but rather is constructed using preexisting elements that provide structure and limitations to the creative process [60, 61]. The concept of creativity is inherently limited by the requirements of novelty and usefulness/effectiveness, as exemplified by the work of Runco and Jaeger [99]. A significant portion of existing academic study has been dedicated to investigating the impact of constraints on creativity, with a particular emphasis on examining focusing constraints. As an illustration, individuals included in certain experimental studies were provided with a certain word that they were required to incorporate into a creative statement [117]. In this particular instance, the level of creativity exhibited in the final result was found to be higher when the search process was constrained compared to when it was not constrained. The complementary nature of limitations is evident in their dual roles of exclusion and focus. These functions often operate in tandem, reinforcing one another [111]. An interesting scenario where constraints help in creativity is the problem of storing vegetables in hot climates, such as India's. The potential constraint arises from the limited availability of refrigeration facilities and, more generally, access to energy. Clay is readily accessible in large quantities. When the material serves as a constraining factor that directs the work of resolving the refrigeration issue, it might facilitate the emergence of innovative solutions such as the utilisation of clay for storage containers [90]. In the laboratory setting, it was seen that participants exhibited more creative outcomes when they were exposed to priming conditions of scarcity, as opposed to really experiencing shortage as a genuine living state [76].

## 1.4 Objective

Through this thesis, we aim

- To examine how constraints in well-defined problem-solving affect ill-defined problem-solving

- To explore the underlying mechanisms that explain the relationship between constraints and creative reasoning
- To understand whether varying constraints in well-defined problem-solving affect ill-defined problem-solving of a different knowledge domain

## 1.5 Thesis Road map

The thesis is constructed in the following way

- Chapter 2 consists of the study ”Do constraints in APM solving affect APM-like puzzle creation?”
- Chapter 3 deals with the extension of the previous study, ”Breaking Domain Barriers: An Inquiry into the Transfer of Induced Creativity”
- Chapter 4 describes the development of interface for the above 2 studies
- Chapter 5 concludes with summary and future directions.

## *Chapter 2*

# Do constraints in APM solving affect APM-like puzzle creation?

## 2.1 Introduction

People encounter various kinds of problems in their day-to-day lives. Some are very open-ended and don't have a definite correct solution. For instance, choosing a dress for a party, a location to visit for the next holiday, or a research problem to work on, to name a few. Such problems are called ill-defined problems. The correctness and acceptance of the solutions depend not only on the problem but on the individuals, social and historical circumstances [14, 112]. Kitchener [67] states that well-defined problems have solutions that are absolutely correct and have a certain guaranteed way of reaching the answer, in contrast, ill-defined problems can have many solutions or none, where the procedural assurance for attaining a solution is not guaranteed.

Flexibility in constraints and varying degrees of freedom in using rules while defining the problem's goal and methods to achieve the solution in an ill-defined problem space allows novel and creative solutions. Such problem-solving is called creative problem-solving, an aspect of creativity in which ill-defined and ambiguous problems tend to allow creative solutions [30, 41]. Creativity has been defined in terms of the production of a "novel product, idea or problem solution that is of value to the individual and/or the larger social group" [53, 80] and involves two modes of thinking, namely, convergent and divergent thinking [17, 47, 79, 55, 56].

During an ill-defined problem solving, divergent thinking is required at the problem's definition, identification, and goal definition stages. However, evaluating and selecting the methods/rules from the knowledge/memory to complete the problem requires convergent thinking. Jaarsveld and van Leeuwen [59] considered convergent thinking in a design process to relate to the (re-) definition of constraints, the evaluation of sub products and the monitoring of progress, while divergent thinking was considered as the creation of new design ideas and the exploration of different compositions. These authors showed that the better designs were the outcomes of creative processes in which i) a relation was observed between the end product and the continuity of the process ii) higher-scoring participants had a better understanding of how close their design had come to its final stage and iii) these participants were more able to give a reliable estimate of their progress.

These observations show that i) training for a better intermingling/cooperation of convergent thinking and divergent thinking abilities could produce better creative solutions to ill-defined problems and ii) less constrained problem definitions lead to more creative problem solutions. Basadur, Graen, and Green [9] reported that training involving synchronization of convergent and divergent thinking in problem construction, idea generation and idea evaluation improves creative problem-solving [81, 10]. Brophy [17] argued that divergent and convergent thinking complement each other which results in creative outcomes. Despite their importance in everyday problem-solving, only a few studies have examined the role of inducing divergent and convergent thinking in ill-defined problem-solving [59, 55, 34].

Majorly, convergent and divergent thinking has been studied separately [58] in the form of intelligence tests (e.g., WAISR-V) [70] and creativity tests (e.g., Guilford's alternate uses task) [125], which restricts us to realize the underlying cognitive processes while approaching well-versus-ill-defined problems. It also creates a friction in realizing the transfer of knowledge from solving well-to-ill-defined problem and vice-versa.

The current study aims to investigate the role of convergent and divergent thinking in creative problem-solving task performance by varying the constraints in traditional problem-solving task, using APM. We developed a novel variant of APM, called *c*APM, to induce both convergent and divergent thinking in the given test. The creative APM uses the standardized APM, with comparatively lesser constraints available to approach the problem. The *c*APM task description is elaborated under the method section. We used the creative reasoning task (CRT) to reduce the variability in the knowledge domain and effectively map the common features while approaching the two problems [56]. It was assumed that if intermingling of convergent and divergent thinking induces creative thinking, then a better CRT score is expected when CRT is preceeded by *c*APM than the traditional APM. We analyzed accuracy for solving APM and *c*APM puzzles, and the NASA TLX [49] self-report of mental demand, physical demand, performance, effort while performing APM puzzles.

We analyzed accuracy for solving APM and *c*APM puzzles. For CRT performance, we analyzed the count and scores of rule components used in creating APM-like puzzle in CRT.

**Table 2.1** NASA TLX Parameters.

| S.No | Parameter |
|---|---|
| 1 | Mental Demand |
| 2 | Physical Demand |
| 3 | Temporal Demand |
| 4 | Performance |
| 5 | Effort |
| 6 | Frustration |

## 2.2 Method

### 2.2.1 Participants

A total of fifty university students (male=49, female=1, others=0, with mean age = 20.60 years, SD = 2.77) volunteered to participate in the study. A participant's data was excluded from *c*APM because they showed less than three correct responses according to our scoring criteria, described below under results section. So the final analysis consisted of 49 participants (25 APM, 24 *c*APM).

### 2.2.2 Material and Design

We selected only six out of the original thirty six APM puzzles for this study. The six puzzles consisted of three pure visuo-spatial and three pure verbal-analytical from Raven's APM. The selection was based on previous research to reduce the variability in representation involved in solving APM puzzles [21] and might influence traditional and *c*APM solving and further CRT performance. The same puzzles were used for both the problem-solving conditions. The description of each test is given below:

#### 2.2.2.1 APM Puzzles

The Raven's advanced progressive matrices (APM) is widely used to measure non-verbal abstract reasoning pertaining to fluid intelligence. The APM puzzles consist of 2 sets. Set I contains 12 puzzles and Set II contains 36 puzzles. For the current study, we selected three visuo-spatial and three verbal-analytical APM puzzles from the set II to reduce the variability of any kind. The three visuo-spatial puzzles comprises 3, 9 and 22 puzzles and three verbal-analytical puzzles comprises 4, 8 and 13 puzzles. The order of the presentation was kept identical to the standard APM puzzle Set II. Each puzzle consisted of a 3 x 3 matrix area with 8 alternative response options, presented below the puzzle. Participants were asked to select the correct response as per their interpretation (Figure 2.1).

#### 2.2.2.2 *c*APM Puzzles

In *c*APM, the participant was provided with only either a single row or column of the same puzzle used for traditional APM in the current study. The eight alternatives in *c*APM were different from traditional APM. These eight alternatives comprise six items corresponding to the original puzzle, along with two most obvious errors. Participants were instructed to deduce the rules from the partially presented puzzle, and complete the puzzle by choosing the eight alternative options presented next to the puzzle (Figure 2.2 and Figure 2.3). The participant had to click and drag the options to the puzzle grid so that it follows the APM rules. Based on the options given, the participant has to extrapolate the rules, check whether the rules work, and then in case the options do not fit, redo the puzzle. The scoring method is described below in the result section.

#### 2.2.2.3 Creative Reasoning Task (CRT)

In CRT, the participant was provided with an empty 3x3 matrix, similar to an APM puzzle, and the participant was asked to create a Raven's like matrix in a given format (Figure 2.4, 2.5) [56]. They were asked to generate the complete puzzle with the answer in the last cell of the puzzle. They were not asked to generate alternatives. The scoring mechanism defined by Jaarsveld and colleagues ( Please refer to the [58]) was used to evaluate the performance of CRT. For this manuscript, the CRT performance was scored using rule component and excluded the element and specification components of CRT total scores.

#### 2.2.2.4 Design

50 participants were randomly allocated to the two independent conditions, APM and *c*APM puzzle-solving, followed by the creative reasoning task (CRT). The experiment was performed in the university experimental lab. One experimenter was present in the room to clarify the doubts raised by participants if any.

#### 2.2.2.5 Apparatus

We used ReactJs and Firebase to create the website to present APM and *c*APM puzzles. However, the CRT was performed using paper pencil, in which participants were asked to first draw an APM-like puzzle in an empty 3x3 puzzle box and second describe their puzzle and also

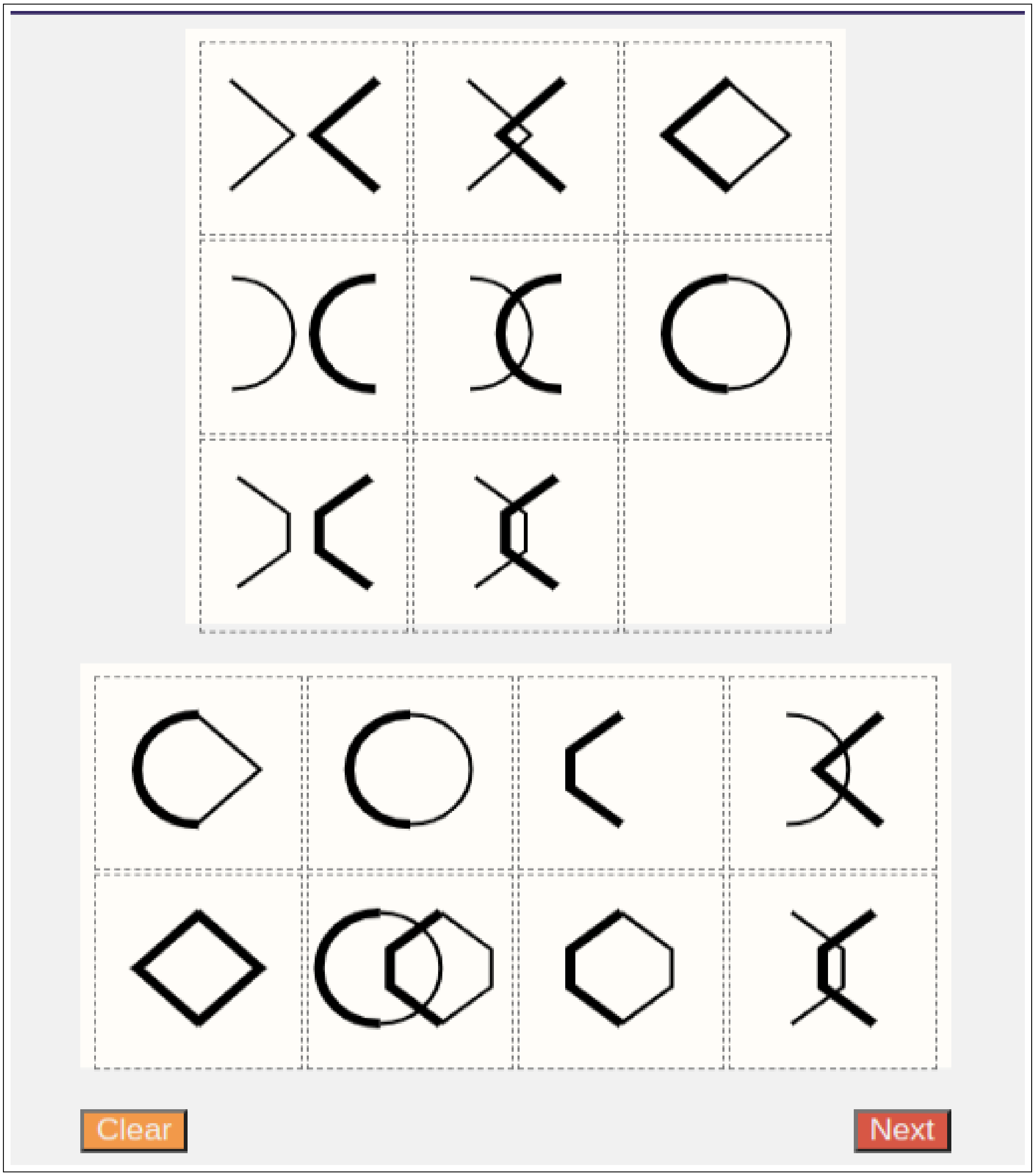


**Figure 2.1** A sample APM puzzle with 8 alternatives. This APM puzzle image is taken from the experiment's website.

give a reasoning why their puzzle is difficult to solve. The CRT sheet recorded participant ID, start time and end time.

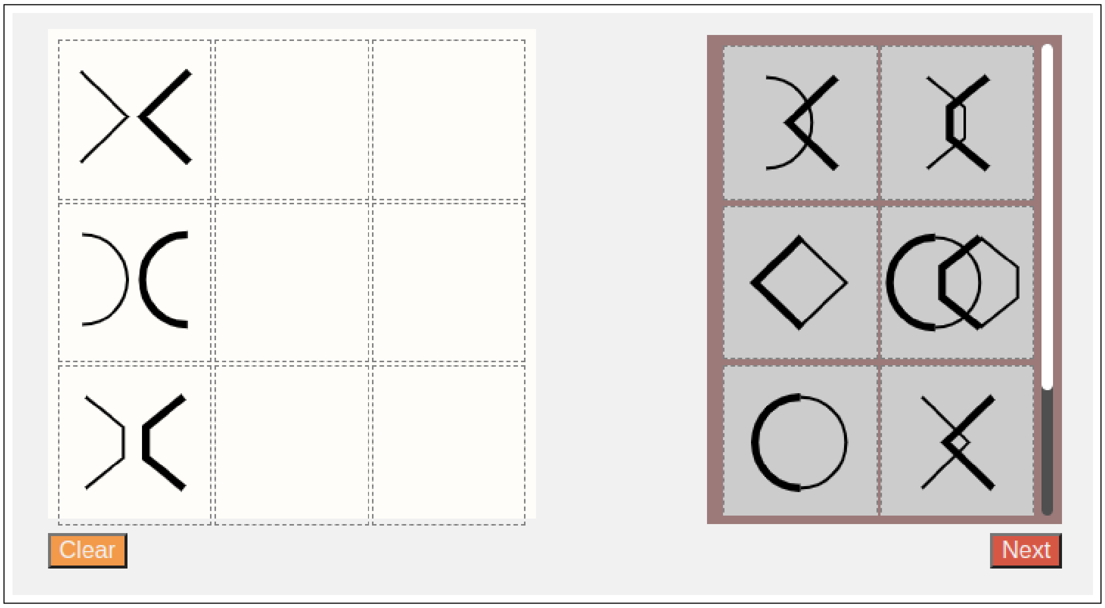


**Figure 2.2** A sample *c*APM puzzle with only one column. The left half consists of the puzzle area and the right half consists of options in the stash. This *c*APM puzzle image is taken from the experiment's website.

#### 2.2.2.6 Procedure

The experiment starts with a welcome note followed by a consent form. After participants gave their consent, they were shown some general instructions followed by collection of demographic information. The participant was randomly assigned to one of the two problem-solving tasks (APM and *c*APM). Based on the problem-solving task, two example problems were given for a better understanding about the upcoming problem-solving task. The problem-solving task consists of six APM/*c*APM puzzles. There was no time constraint for the problem-solving task. Participants were free to take their time to solve the puzzles. Once the problem-solving task finished, participants were asked to perform CRT. CRT form was handed over to them in paper along with a questionnaire to describe their CRT puzzle and why their puzzle is difficult to solve. The CRT test and the follow up questionnaire was the only part of the experiment which is performed on paper. All the remaining tasks were performed on computer using the website. The final section of the experiment was the feedback section which consisted of a NASA TLX [49] and feedback about the website's UI. Participants also had the option to give additional feedback if any.

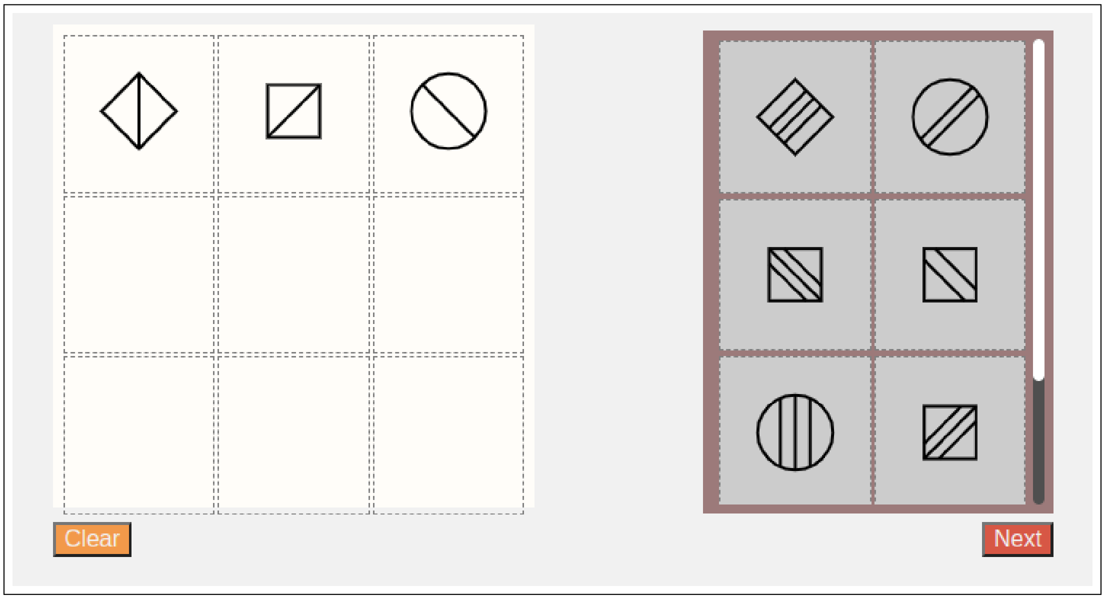


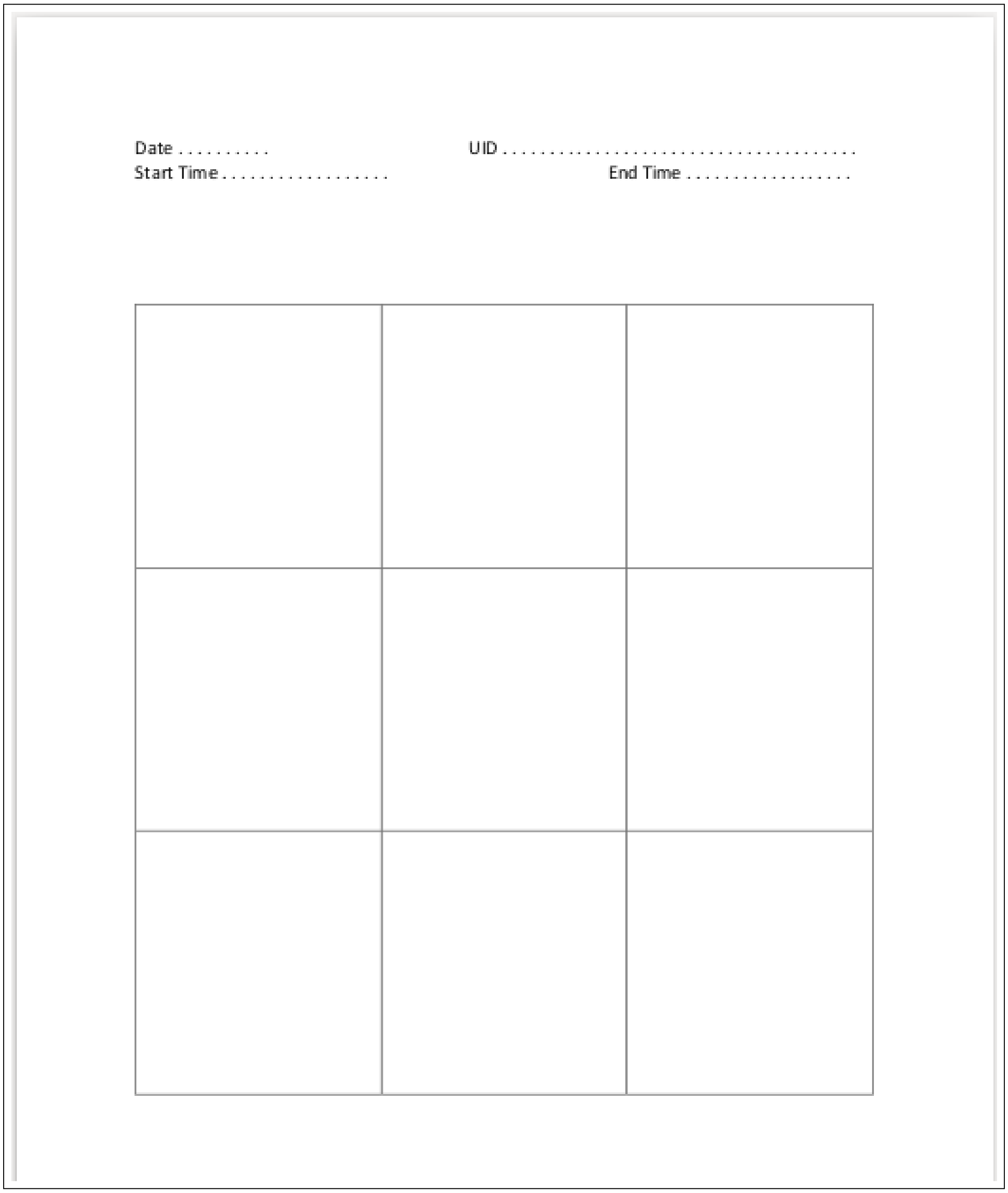
**Figure 2.3** A sample *c*APM puzzle with only one column. The left half consists of the puzzle area and the right half consists of options in the stash. This *c*APM puzzle image is taken from the experiment's website.

## 2.3 Results

The problem-solving performance for both the groups was scored using the binary scoring method. For the APM puzzle, the correct response was scored "1", and the incorrect response scored "0". For the *c*APM puzzle, if all the rules present in the original APM puzzle were present in the *c*APM results, then it was scored "1", otherwise "0". To be considered for statistical analysis, the cutoff was kept at 50%. This means that participants should have solved at least 3/6 puzzles correctly under APM and *c*APM conditions. The CRT performance was scored using Jaarsveld and colleagues [58] scoring method. We analyzed only two aspects of CRT: a. the counts of rules, and b. the score to calculate the relationship between the elements.

### 2.3.1 Problem-Solving Performance (APM vs *c*APM)

We observed violations of normality assumptions by using the Shapiro-Wilk test for both groups, *c*APM (W = 0.89, $p = 0.013$) and APM (W = 0.81, $p < 0.001$). This led to choosing non-parametric analysis. Mann-Whitney U test showed a significant effect of varying constraints on well-defined problem-solving i.e, APM and *c*APM on the task performance with large standardized effect size (U = 532.5, $p = 0.00000146$, $r = 0.69$). The results showed a



Date . . . . . . . . . .
UID . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
Start Time . . . . . . . . . . . . . . . . .
End Time . . . . . . . . . . . . . . . . .

**Figure 2.4** CRT Form

higher accuracy score for APM condition (*Median* = 5/6) than *c*APM condition (*Median* = 4/6) (Figure 2.6).

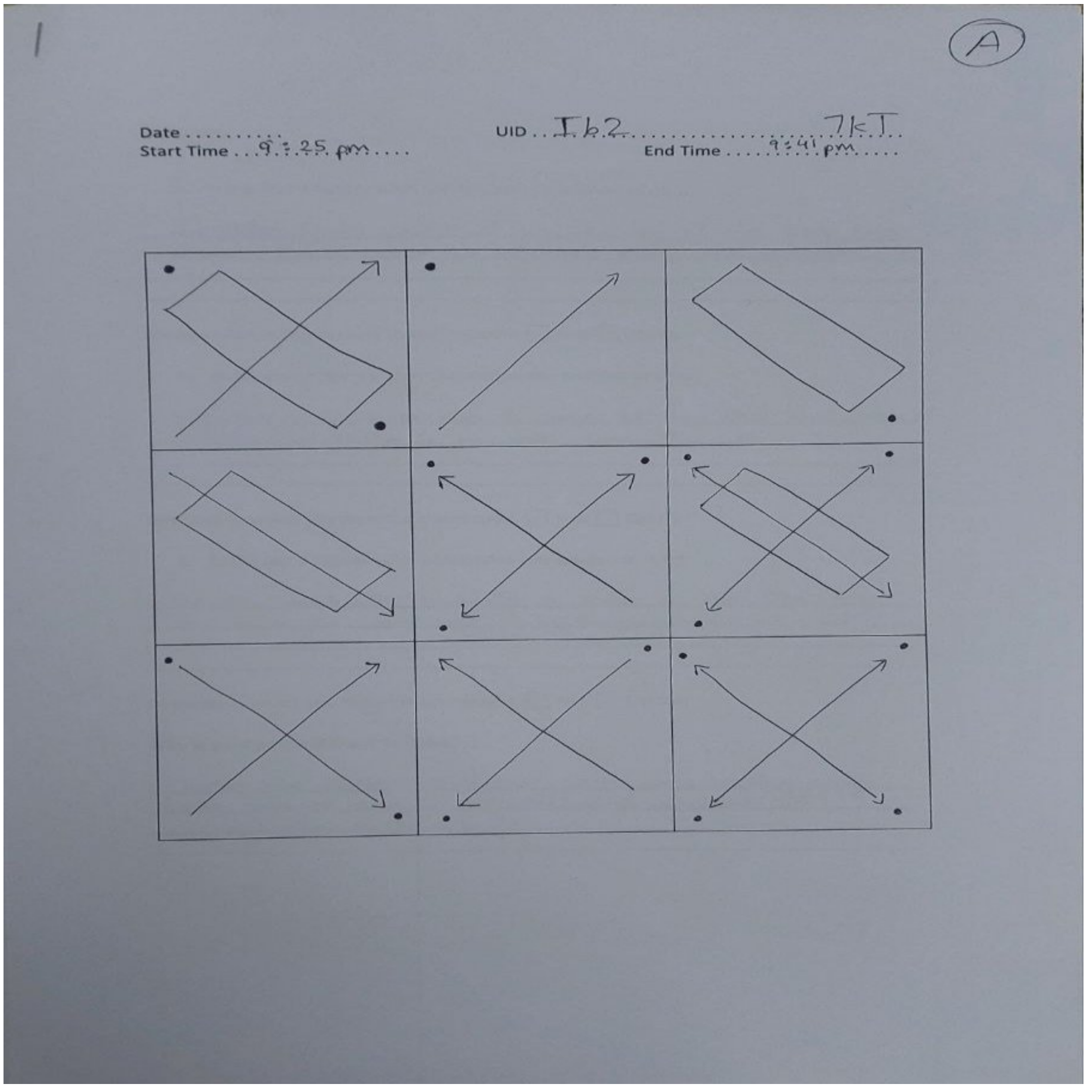


**Figure 2.5** A sample CRT puzzle by a participant

### 2.3.2 CRT Performance

The CRT Performance was measured using two parameters i) Number of rules applied in CRT ii) CRT Relationship Score. Two participants from APM and two participants from *c*APM group were excluded for CRT analysis because they used numbers instead of geometric and line components. This led to a total of fourty five participants for the CRT analysis. We calculated the number of rules used in the CRT, and the relationship scores by employing these rules between the geometrical and line elements.

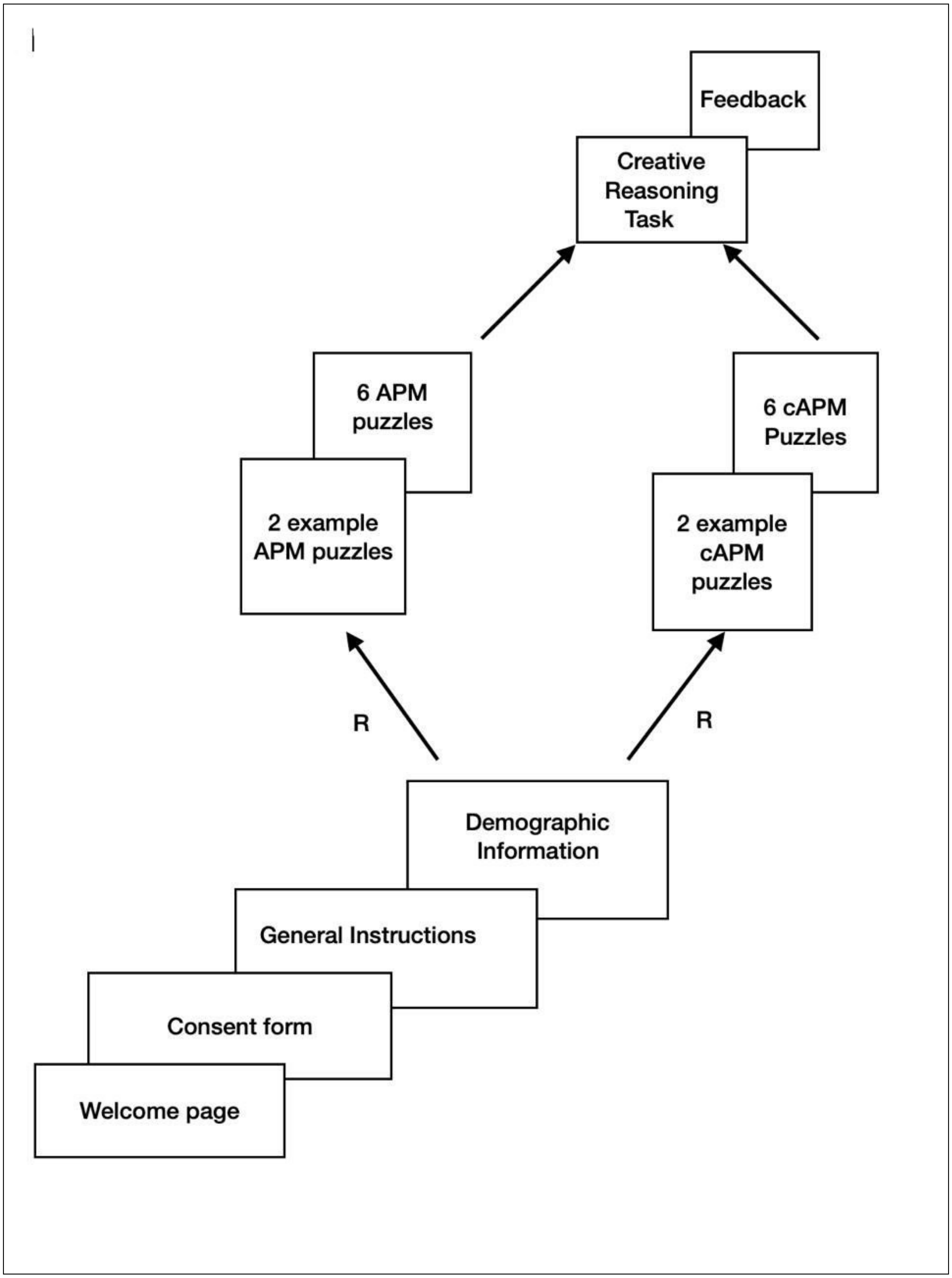


**Figure 2.6** The schematic flow of the overall experiment. R = random assignment

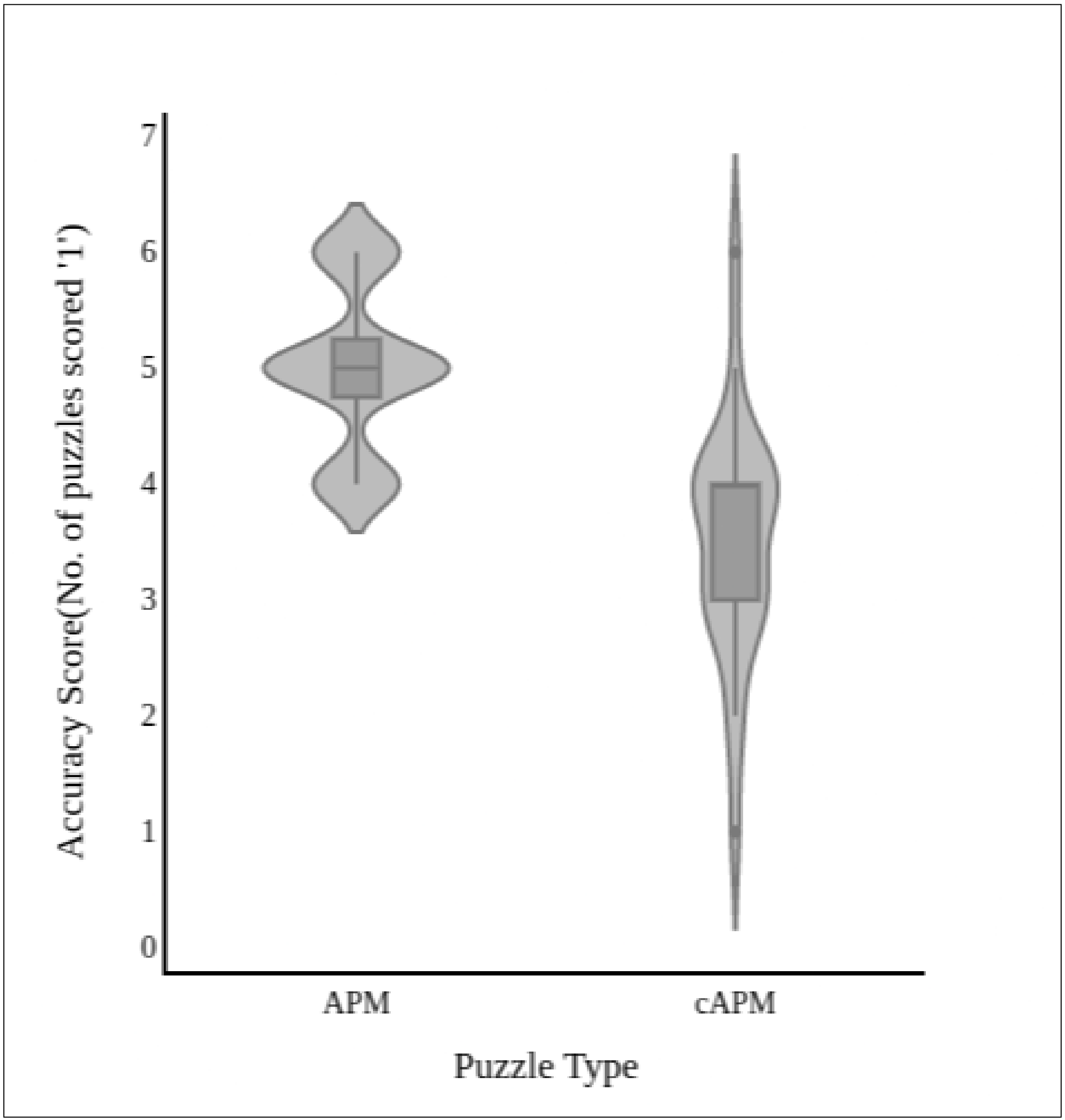


**Figure 2.7** Accuracy scores b/w APM and *c*APM

#### 2.3.2.1 Number of Rules in CRT

The Shapiro-Wilk test for both groups indicated violation of normalcy for CRT scores, *c*APM (W = 0.88, $p = 0.014$) and APM (W = 0.73, $p < 0.001$), and led us to choose non-parametric analysis. Mann-Whitney U test showed significant effect of varying constraints in APM puzzle (i.e., APM with high constraints and *c*APM with lesser constraint) on the number of rules used in CRT with medium standardized effect size (U = 125.0, $p = 0.002$, $r = 0.46$). Participants used more number of rules in CRT when they solved APM with lesser constraints of rules, i.e., *c*APM

(*Median*=2) than traditional APM (*Median*=1) (Figure 2.7). We conducted a permutation test with 10000 samples and found the result to be statistically significant($p = 0.002$).

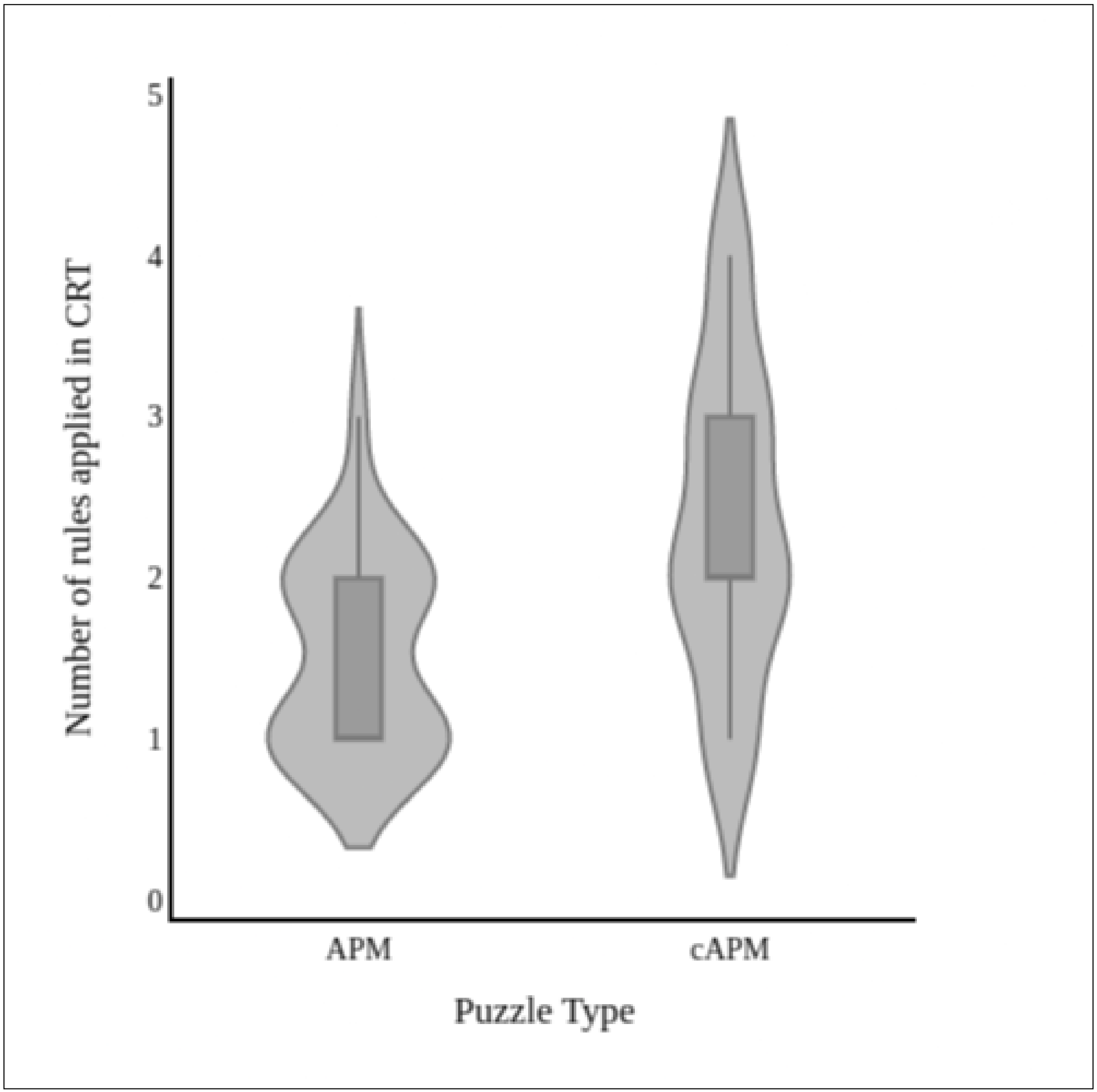


**Figure 2.8** Number of rules applied in CRT after solving *c*APM and APM

#### 2.3.2.2 CRT Relationship Score

We observed a significant violation of normalcy for CRT relationship score for both groups, *c*APM (W = 0.79, $p < 0.001$) and APM (W = 0.87, $p = 0.006$) and therefore performed non parametric analysis. The *c*APM group showed a significantly higher CRT relationship score (*Median* = 79.25) than APM (*Median* = 53.00) with a medium standardized effect size (U =

141.5, $p = 0.011$, $r = 0.38$) (Figure 2.8). We conducted a permutation test with 10000 samples and found the result to be statistically significant($p = 0.0118$).

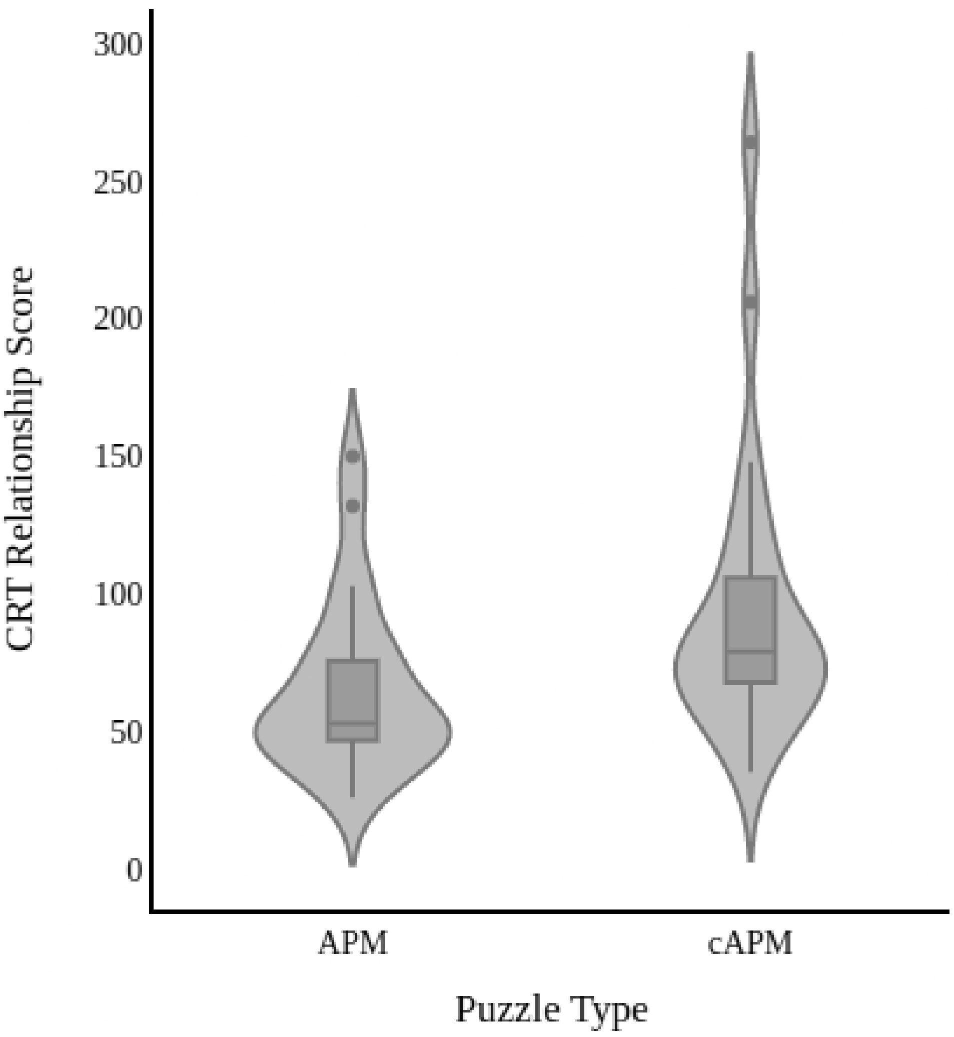


**Figure 2.9** CRT Relationship scores after solving *c*APM and APM.

## 2.4 Discussion

The current study examined the role of constraints in well-defined problem-solving in the ill-defined creative problem-solving task performance. The well-defined problem-solving was measured using the variant of APM [93], and ill-defined problem-solving was measured using

CRT [56]. We created a variant of traditional APM, called creative APM (*c*APM), in which the rules to deduce the relationship between elements of the given puzzle were not as well-defined as in traditional APM. We assumed that *c*APM, unlike traditional APM, will induce divergent thinking in well-defined problem space, as it demands creating a puzzle based on the reasoning deduced by partial information, either row or column. In traditional APM, participants are presented with a 3x3 matrix and are allowed to exhaust all the possible rules to complete the puzzle with a single missing piece. Therefore, the correct response leads to a single answer. Whereas in *c*APM the participants are presented with either a row or a column. The partial information allows more degree of freedom in the puzzle's completion. Only a row or column present to deduce the rules leads to a few alternative responses, despite a fixed number of correct answers at the end.

The *c*APM completion demands searching for the rules and the elements and requires participants to create a puzzle, which may entail different cognitive processes than traditional APM. The search for rules and the constant evaluation of the relationship between the elements as the puzzle builds up demands juggling between convergent and divergent thinking. It is assumed that the search for rules in *c*APM requires selective processes to filter the irrelevant features (attention and executive control function) and keeping the relevant information for future use (working memory) demands manipulation and adjustment between various options before a puzzle completion. Therefore, the processes involved in *c*APM appear closer to the CRT, in which participants are asked to create an APM-like puzzle from scratch, and may facilitate CRT performance when asked to perform *c*APM be- fore CRT than traditional APM. The higher CRT score when the CRT followed the *c*APM than the traditional APM is consistent with our hypothesis, suggesting that the *c*APM allows participants to involve in similar cognitive processes that CRT demands and therefore shows a better CRT performance than when it follows traditional APM.

We chose APM to study well-defined problem-solving because of the shared knowledge domain with CRT. Recently, a study [56] argued the importance of reducing the variability in intelligence and creativity tests (corresponding to well-and-ill-defined problem space) to better understand the shared and distinct cognitive processing underlying these two problem spaces. The authors [56] argue in favor of keeping the knowledge domain constant, realizing the inevitable difference between the constructs and problem spaces. The CRT was chosen because a. it shares the knowledge domain with the APM, and b. it's the only test in creative thinking that allows both convergent and divergent thinking in a single test. Previous studies [56, 34] using traditional APM and CRT have shown a strong correlation between convergent scores of CRT and traditional APM [55] and a strong correlation between divergent thinking score of CRT and widely used creative thinking task, test for creative thinking and drawing production (TCT-DP), indicating the use of divergent and convergent thinking in CRT at different stages.

It is concluded that the flexibility in constraints to solve the well-defined problem facilitates the following ill-defined problem-solving task performance. Despite encouraging behavioral data, the underlying shared cognitive mechanism and associated neural correlates demand further investigation. It is assumed that tests like APM, *c*APM, and CRT will allow better examination of the well-and-ill-defined relationship in future. An interesting follow up study would be ”Does flexibility in constraints to solve the well-defined problem impact ill-defined problem if both tasks are from different knowledge domain?”.

## 2.5 Additional Results

### 2.5.1 Average Toggle Count for *c*APM Puzzles

Puzzle 6(22 in the APM puzzles) has the highest average toggle count(60.16) which is more than the double of second highest average toggle count(26.29 for puzzle 4((9 in the APM puzzles)))

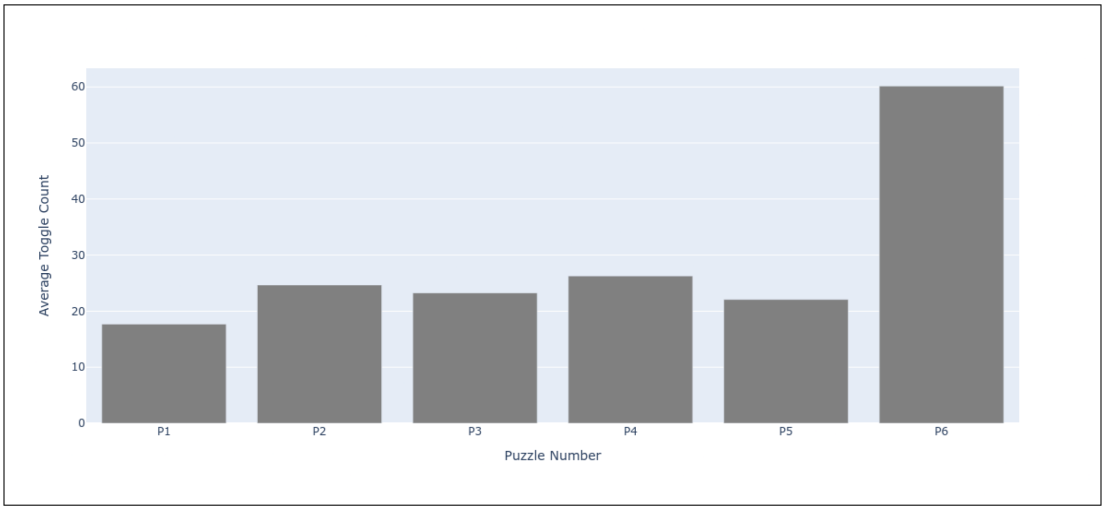


**Figure 2.10** Toggle Count for *c*APM Puzzles

### 2.5.2 CRT Relationship Scores vs Time(in min)

A positive correlation was found between the CRT Relationship Scores and Time(R = 0.43), but the relationship is weak.

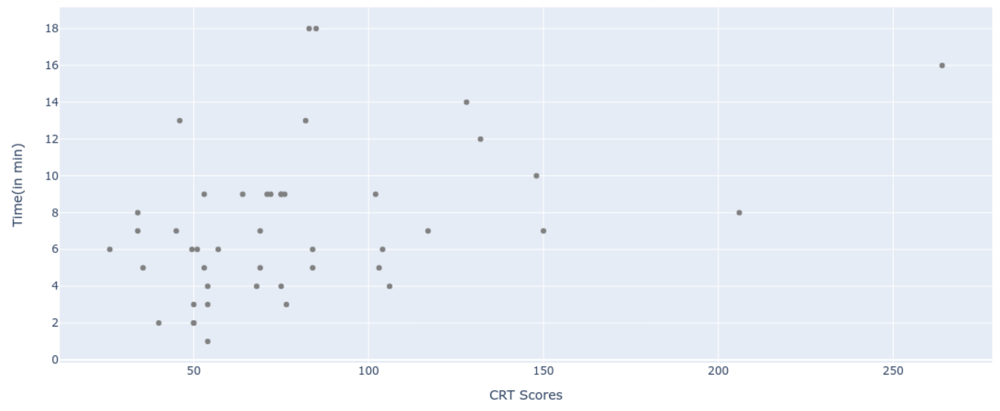


**Figure 2.11** CRT Relationship Scores vs Time(in min)

### 2.5.3 Effort reported by participants after solving *c*APM and APM.

We observed a significant violation of normalcy for self-reported effort for both groups, *c*APM (W = 0.89, $p$ = 0.014) and APM (W = 0.89, $p$ = 0.014) and therefore performed non parametric analysis. We failed to observe a significant effect of varying constraint on APM puzzle solving(U = 216.0, $p$=0.05).

### 2.5.4 Performance reported by participants after solving *c*APM and APM.

We observed a significant violation of normalcy for self-reported performance for both groups, *c*APM (W = 0.88, $p$ = 0.008) and APM (W = 0.84, $p$ = 0.0012) and therefore performed non parametric analysis. We failed to observe a significant effect of varying constraint on APM puzzle solving(U = 328.0, $p$=0.76).

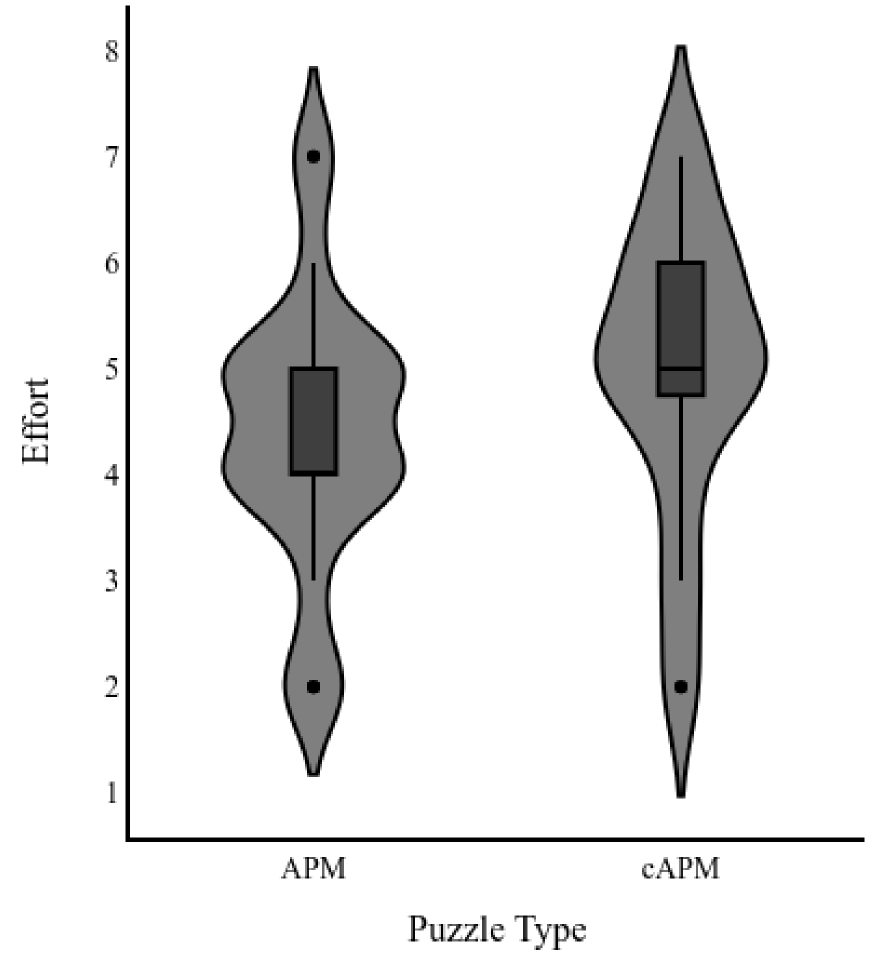


**Figure 2.12** Effort reported after solving *c*APM and APM.

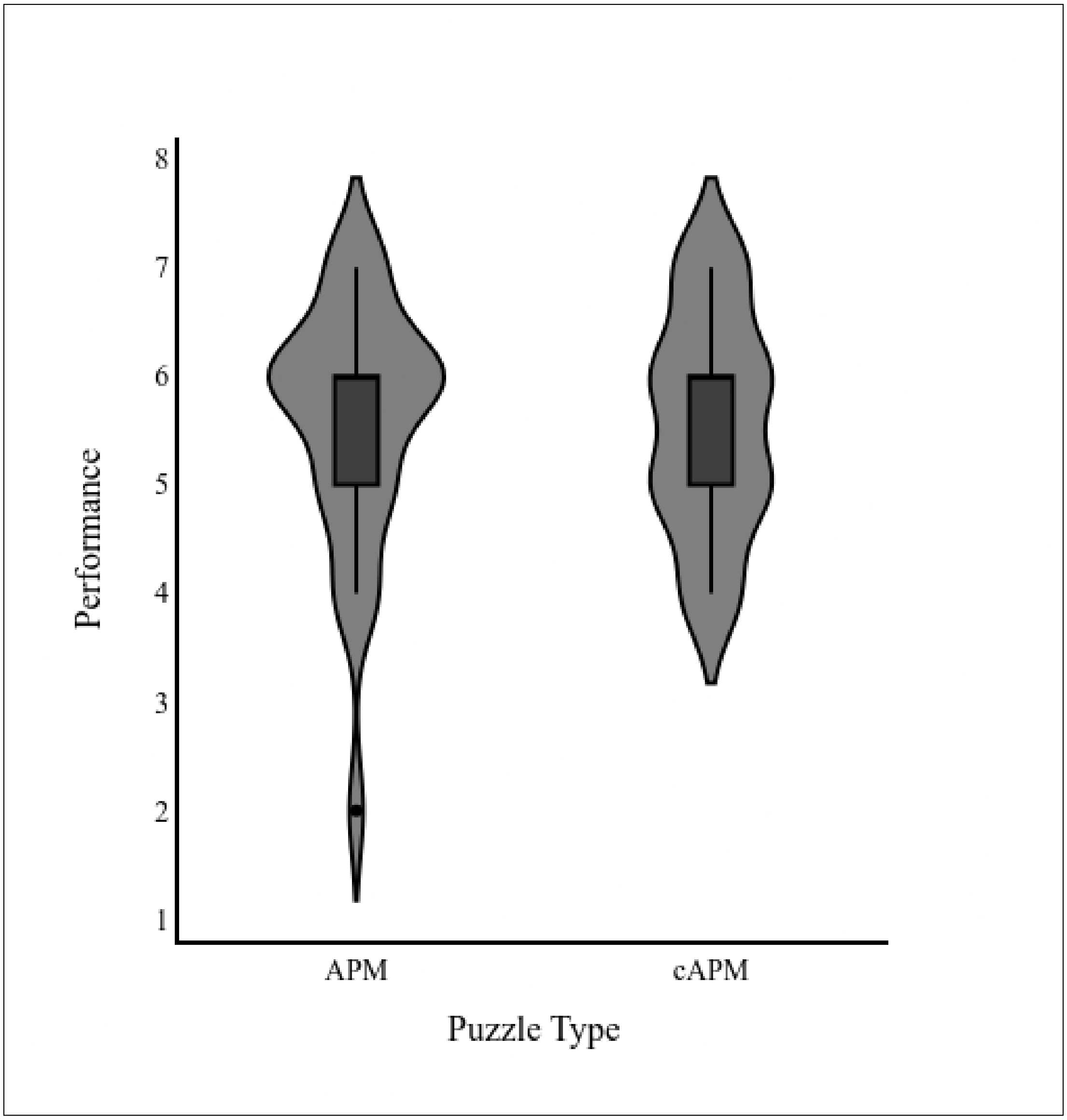


**Figure 2.13** Performance reported after solving *c*APM and APM.

## *Chapter 3*

# Breaking Domain Barriers: An Inquiry into the Transfer of Induced Creativity

## 3.1 Introduction

Human intelligence, in all its complexity and richness, is a subject that continues to intrigue researchers and scholars across the globe. Its multi-faceted nature has given rise to diverse theories and conceptual models that aim to understand the underlying cognitive processes and abilities encompassed within it. Among these abilities, problem-solving and creativity are two constructs that have been studied extensively, with various tools and tests devised to probe their underlying mechanisms. One such tool, Raven's Advanced Progressive Matrices (APM) [92], has been widely employed to gauge an individual's capacity for abstract reasoning, a core aspect of fluid intelligence [19]. The underlying cognitive processes that the APM test taps into are manifold. First and foremost, it requires abstract reasoning and problem-solving skills to identify patterns and relationships among the visual elements in the matrix [71]. This involves deducing rules and principles based on the given information, a process that engages the brain's executive functions [83].For example, in APM, participants are expected to identify the missing segment of a complex pattern or sequence from several given alternatives involving convergent thinking. This requires the application of a rule-based, analytical approach that operates within the constraints of the problem structure and the given options [107]. But what would be the implications if these constraints were modified? Could this restructuring facilitate the transition from convergent to divergent thinking, and in turn, foster creativity?

A recent study has shown that varying constraints in well-defined problem solving task influence creative problem solving task performance [4]. In this study, two groups of participants were asked to solve the traditional APM and creative APM (*c*APM) separately. The *c*APM is designed using traditional APM but with fewer constraints to solve the puzzle. After solving APM and *c*APM, both groups were then asked to create Raven's like matrices using a creative reasoning task (CRT) [58]. The group with fewer constraints performed better in the creativity task. However, it is important to note that both tasks, Raven's matrices and creating a Raven's like matrice, belonged to the same knowledge domain [4]. This raises a concern of whether varying constraints in *c*APM is limited to CRT or else influence the creative task performance from different knowledge domains. So, can this induction also impact a creativity task from different knowledge domain?

Knowledge-domain can be a double-edged sword. It can offer direction when coming up with fresh ideas that are suitable for the current task, but it can also stifle creativity by limiting originality [122]. For example, if the task was to design a better smartphone, a smartphone manufacturer would improve the storage capacity or camera quality compared to the previous version. This can be described as an instance of conceptual expansion where individuals expand the limits of an existing conceptual area by creating new examples within that area [123]. If the same task was given to a person with no knowledge about designing smartphones, the resulting output would be unpredictable. A previous study also concluded that people who relied on preexisting ideas or structures produced less original designs [122].

Is creativity domain-specific or domain-general? Significant studies have approached this problem using self-reported personality and domain-specific and general creative ideation surveys and lack cognitive perspectives [11]. Creativity is defined as the generation of original and useful products that have emerged through the applications of basic cognitive processes to existing knowledge structures. The current study investigates its implications while modifying the basic knowledge structure. Further, we examine the role of the knowledge domain in creative task performance. For prior knowledge structure, we used advanced Raven's matrices and modified its constraints to create a novel creative advanced Raven's Matrices (*c*APM) to induce creativity. For creativity, we asked participants to perform two tasks: create Raven's like matrices using creative reasoning task (CRT) and Guilford's alternative uses task (AUT). Unlike other creativity tasks like AUT, CRT allows to measure both convergent and divergent thinking in a given task. The CRT and AUT are different from APM puzzles in two ways, i.e., the knowledge domain and the involvement of creative thinking. The fixed order of APM followed by creativity tasks allowed us to evaluate the boundaries of induced creative thinking across the knowledge domain.

## 3.2 Method

### 3.2.1 Participants

Total forty four students (male=24, female=20, others=0 with mean age = 19.8 years, SD = 1.7) volunteered for the study. The participants were recruited via email under course credit requirements.

### 3.2.2 Materials

#### 3.2.2.1 APM Puzzles

APM puzzle comprises a 3 x 3 matrix area with 8 response options, presented below the puzzle. The response options contained one correct puzzle, two most obvious errors, two least obvious errors, and three random error choices. The participant had to choose the puzzle cell that best fit the overall puzzle. The correct response was scored “1”, and the incorrect response scored “0”. We presented six such puzzles.

#### 3.2.2.2 *c*APM Puzzles

Creative APM (*c*APM) is a modified version of the classic APM with reduced constraints. The purpose of the *c*APM task was to stimulate both divergent and convergent thinking. In *c*APM, the participant was provided with only a single row/column of the puzzle, along with eight options for the six empty spaces. The participant had to click and drag the options to the puzzle grid so that it follows the APM rules. There are multiple approaches to solve the puzzle as there are multiple ways to interpret the different rules provided in the given row/column and available options. The *c*APM results were scored as ”1” if all the rules from the original APM puzzle were present, and ”0” if they were not. The time taken to solve all the *c*APM puzzles($Median$ = 9 minutes, 14 seconds) is higher compared to the APM puzzles($Median$ = 3 minutes, 9 seconds).

#### 3.2.2.3 Creative Reasoning Task (CRT)

During the Creative Reasoning Task (CRT), participants were given an empty 3x3 matrix, mirroring an APM puzzle, and asked to construct a matrix similar to Raven’s within a specified format [56]. The task required them to devise a complete puzzle, with the solution located in the final cell. Generating alternatives was not a requirement. The scoring methodology, as outlined by Jaarsveld and her team (please see [58] for reference), was employed to assess CRT performance. For the purposes of this paper, we scored the CRT performance using only the rule component, leaving out the element and specification components from the total CRT scores.

#### 3.2.2.4 Alternate Uses Task (AUT)

The Alternate Uses Task (AUT) is a classic test of creativity, originally developed by J.P. Guilford in the 1960s, widely used in psychological research to measure divergent thinking - a type of cognitive process that generates creative ideas by exploring many possible solutions. In this task, participants are asked to list as many uses as possible for a common object, such as a brick or a paperclip, within a certain time frame. The goal is to come up with unique and diverse uses for the object, pushing beyond its typical or conventional uses. In the current study, we have used 6 items namely 1) brick 2) shoe 3) newspaper 4) spoon 5) ladder 6) tennis ball. The experiment consists of 2 phases. In Phase 1, participants are asked to come up with as many creative uses as possible for the each item within 2 minutes. After the phase 1, the computer lists all provided uses for each object and participants are asked to select the top 2 uses for each item.

The responses are typically evaluated based on four factors:

- **Fluency**: The total number of uses generated.
- **Flexibility**: The number of different categories that the uses fall into.
- **Originality**: The uniqueness of the responses, compared to responses from other participants.
- **Elaboration**: The amount of detail in the responses, or how well-developed the ideas are.

By measuring these factors, the AUT helps assess an individual's capacity for divergent thinking and their potential for creative problem-solving.

#### 3.2.2.5 Design

The participants were randomly assigned to one of the two independent experimental conditions - solving either the APM or the *c*APM puzzle - each followed by the Creative Reasoning Task (CRT) and Guilford's Alternate Uses Task(AUT). Participants performed the variant of APM first and CRT and AUT task in consecutive order. The order was kept fixed to evaluate the effect of varying constraints in APM on creative task performances across CRT and AUT. The APM, *c*APM and CRT tasks share knowledge domain, whereas AUT is different in knowledge domain.

#### 3.2.2.6 Apparatus

To present the APM and *c*APM puzzles, we developed a website using ReactJs and Firebase. On the other hand, the Creative Reasoning Task (CRT) was conducted in a traditional paper-and-pencil format. Participants were instructed to craft a puzzle similar to an APM within an empty 3x3 box and then provide a description of their puzzle. They were also required to justify why they believed their puzzle posed a significant challenge to solve. Each CRT sheet was marked with the participant's ID and both the start and end times of the task. The AUT task was performed on the computer screen.

#### 3.2.2.7 Procedure

The experiment initiated with a welcoming message, followed by a consent form. Once participants provided their consent, they were presented with general instructions and a request for demographic information. Subsequently, each participant was randomly assigned to one of the two problem-solving tasks, either APM or *c*APM. Based on this assignment, two sample problems were provided to aid participants in understanding the forthcoming task. This problem-solving segment consisted of six APM/*c*APM puzzles and was not time-bound, allowing participants to take as long as they needed to solve the puzzles.

Upon completion of the problem-solving task, participants moved on to the Creative Reasoning Task (CRT). They were given a CRT form in paper format, along with a questionnaire asking them to explain their CRT puzzle and justify why it presents a challenge to solve. Following the CRT task, participants were presented with AUT task. This CRT segment and the follow-up questionnaire were the only components of the experiment conducted on paper. All other tasks were computer-based, using a designated website. The concluding part of the experiment included a feedback section, featuring the NASA TLX [49] and a survey regarding the website's user interface. Additionally, participants were given the opportunity to provide any further comments or feedback they may have had (Figure 3.1).

## 3.3 Results

The Alternate Uses Task performance is compared between both the groups. For the current study, we have analyzed only the Fluency and Elaboration scores.

### 3.3.1 AUT Performance

#### 3.3.1.1 AUT Fluency Score

The fluency score for both groups, APM($W = 0.97$, $p = 0.71$) and *c*APM($W = 0.96$, $p = 0.66$) didn't violate the normality assumptions. An independent t-test was performed between both groups and no significant difference was observed($p = 0.80$) with a small effect size($d = 0.074$). This result indicates that constraints in training doesn't have an impact on the creativity task of different knowledge domain (Figure 3.2).

#### 3.3.1.2 AUT Elaboration Score

The elaboration score was calculated as the summation of the number of words in each use case for all use cases. The Shapiro-Wilk test revealed that both groups had deviations from normality in their elaboration scores, with *c*APM ($W = 0.88$, $p = 0.015$) and APM ($W = 0.90$, $p = 0.04$). The Mann-Whitney U test revealed no statistically significant impact of different

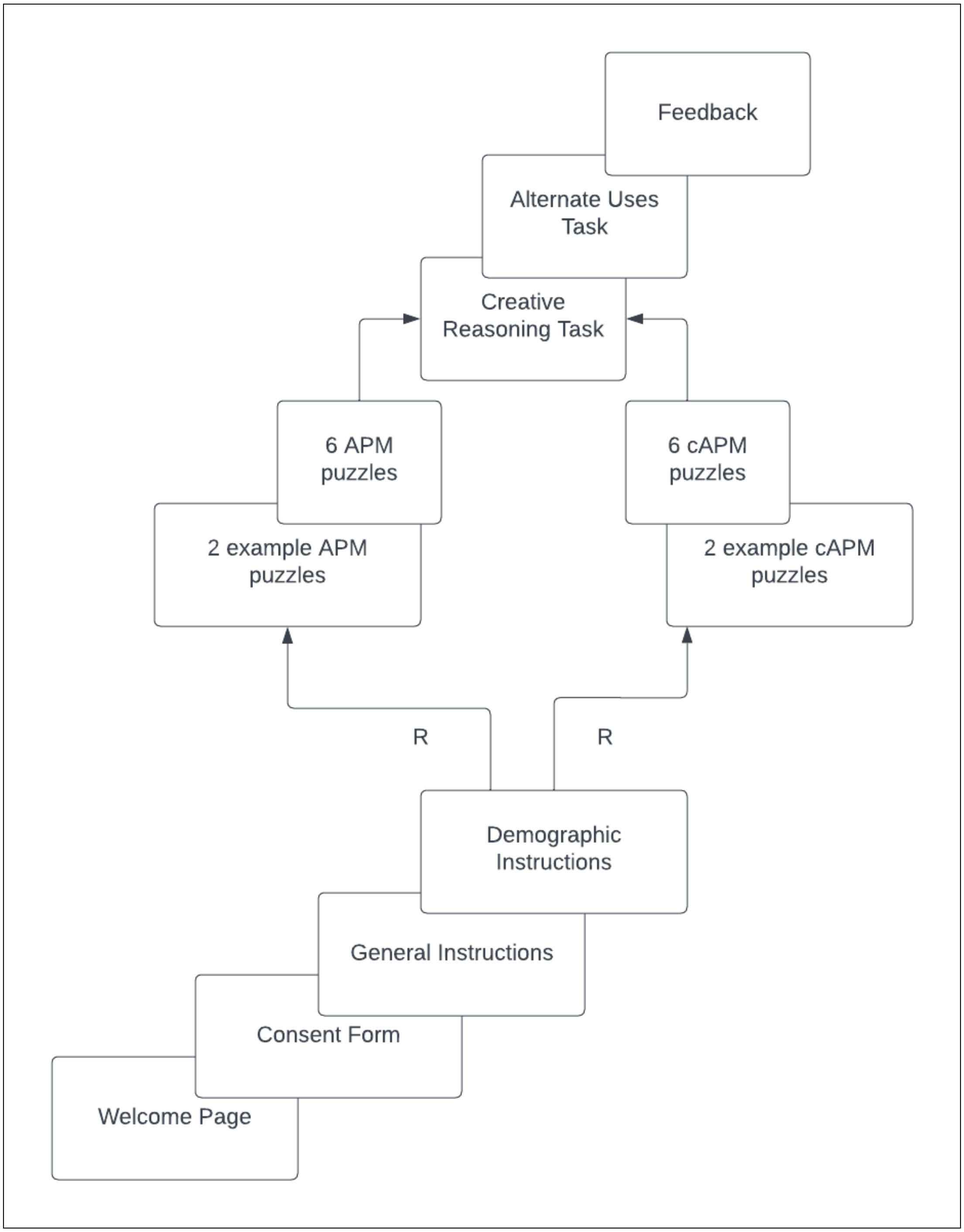


**Figure 3.1** AUT Fluency score b/w APM and *c*APM

constraints in the APM puzzle on the Elaboration Score. The observed standardized effect size is small ($p = 0.48$, $r = 0.11$) (Figure 3.3).

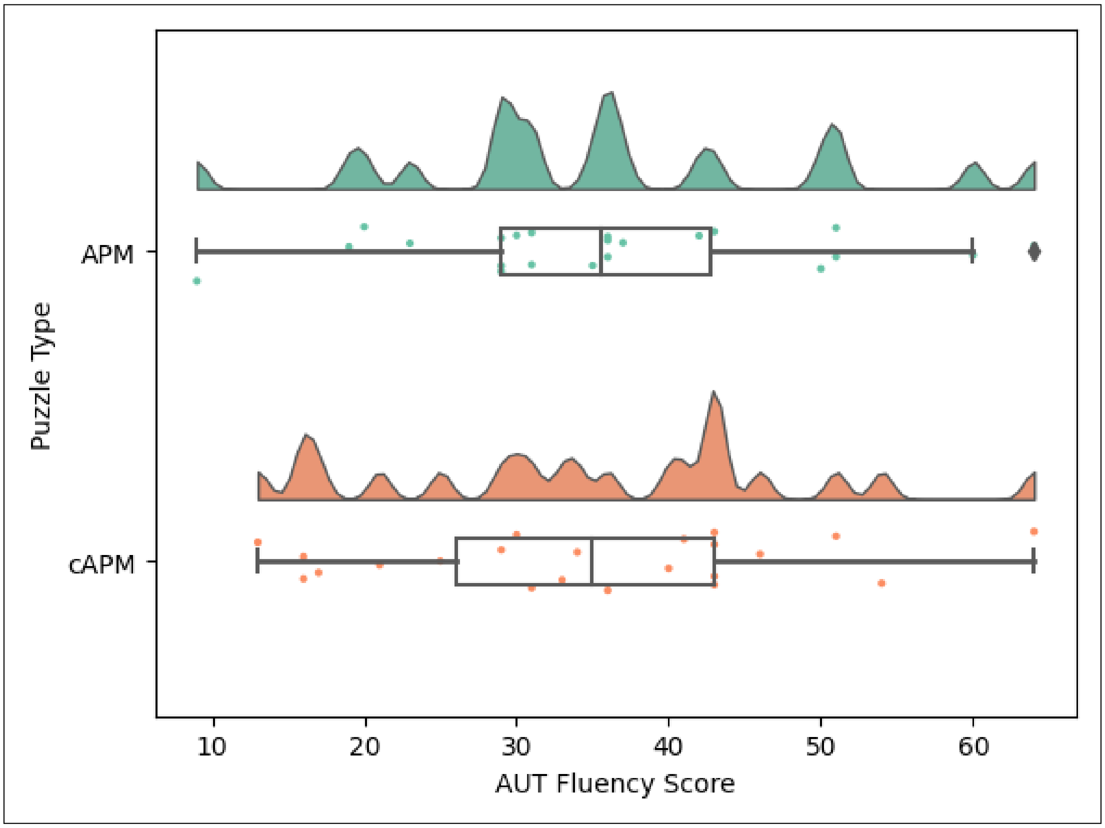


**Figure 3.2** AUT Fluency score b/w APM and *c*APM

## 3.3.2 CRT Performance

### 3.3.2.1 Number of Rules in CRT

The Shapiro-Wilk test revealed that both groups had deviations from normality in their number of rules in CRT, with *c*APM (W = 0.84, $p = 0.003$) and APM (W = 0.70, $p < 0.001$). The Mann-Whitney U test revealed a statistically significant impact of different constraints in the APM puzzle on the number of rules utilized in the CRT. The standardized effect size was found to be medium (U = 394.0, $p < 0.001$, $r = 0.58$). The participants demonstrated a higher number of rules in the CRT when they solved *c*APM($Median = 2$) compared to the traditional APM($Median = 1$). We conducted a permutation test with 10000 samples and found the result to be statistically significant($p < 0.001$) (Figure 3.4).

### 3.3.2.2 CRT Relationship Score

The Shapiro-Wilk test for the APM group(W = 0.92, $p = 0.11$) was performed and did not show evidence of non-normality. The Shapiro-Wilk test revealed that the *c*APM group (W =

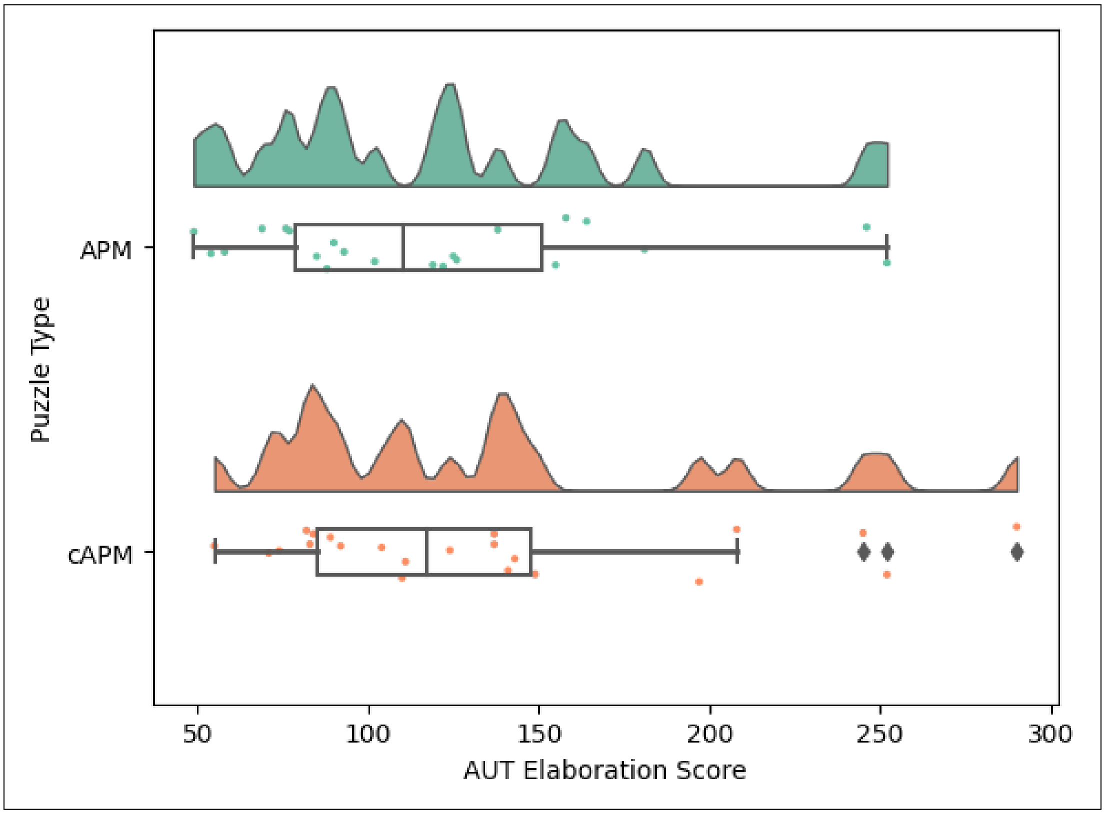


**Figure 3.3** AUT Elaboration score b/w APM and *c*APM

0.81, $p = 0.0007$) had deviated from normality. The Mann-Whitney U test revealed a statistically significant impact of different constraints in the APM puzzle on the CRT Relationship Score. The standardized effect size was found to be large (U = 393.5, $p < 0.001$, $r = 0.54$). The participants demonstrated a higher CRT Relationship Score when they solved *c*APM(*Median* = 78.5) compared to the traditional APM (*Median* = 50.5). We conducted a permutation test with 10000 samples and found the result to be statistically significant($p < 0.001$) (Figure 3.5).

### 3.3.3 Additional Results

#### 3.3.3.1 AUT Fluency Score (vs) CRT Relationship Score

A negative correlation was found between the CRT Relationship Scores and AUT Fluency Score(R = -0.083), but the relationship is weak (Figure 3.6).

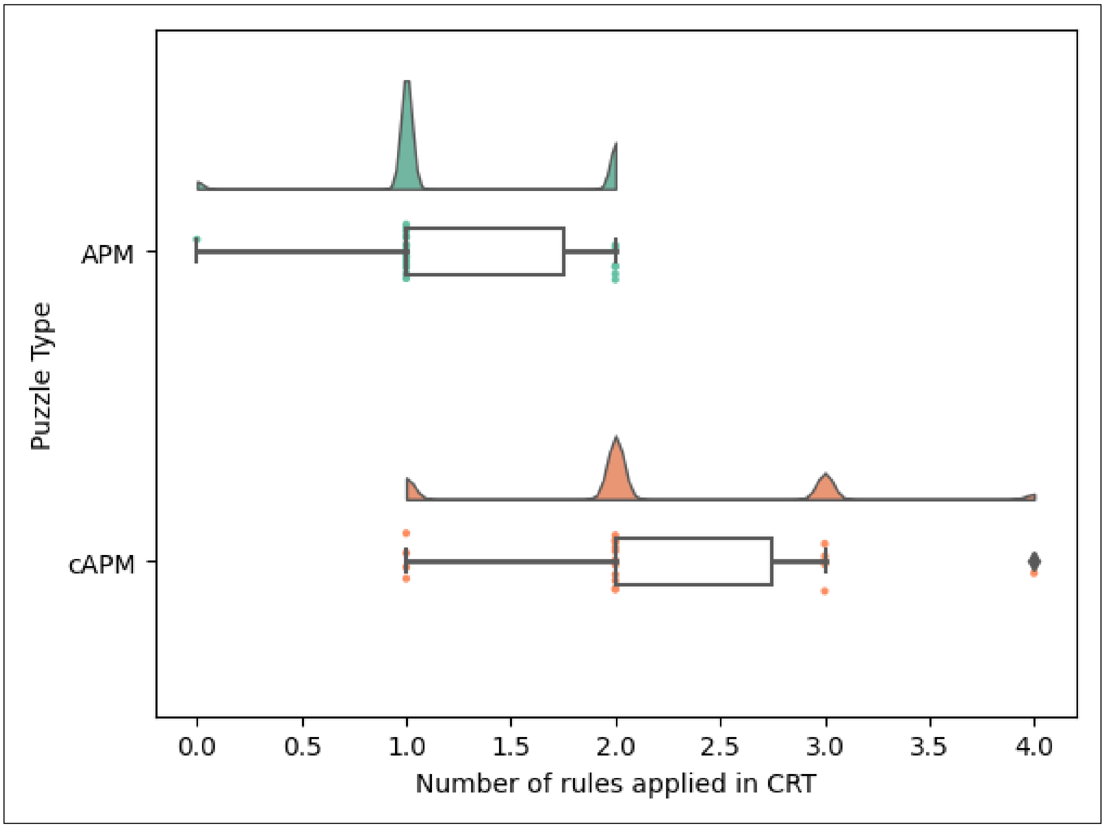


**Figure 3.4** Number of rules applied in CRT after solving APM and *c*APM

#### 3.3.3.2 AUT Fluency Score (vs) Number of Rules in CRT

A positive correlation was found between the Number of Rules in CRT and AUT Fluency Score($R = 0.056$), but the relationship is weak (Figure 3.7).

## 3.4 Discussion

This study examined the role of constraints in well-defined problem-solving in the ill-defined creative problem-solving task performance of a different knowledge domain. APM and *c*APM were chosen for the well-defined problem-solving task similar to the previous study. For the ill-defined problem-solving task, along with CRT, we have added Alternative Uses Test(AUT). CRT belonged to the same knowledge domain of APM and *c*APM, whereas AUT was of a different knowledge domain. One of the most important cognitive strategies required to solve CRT and AUT is divergent thinking. As *c*APM involved creating a puzzle using logic inferred from either row or column of incomplete information, we assumed divergent thinking will be

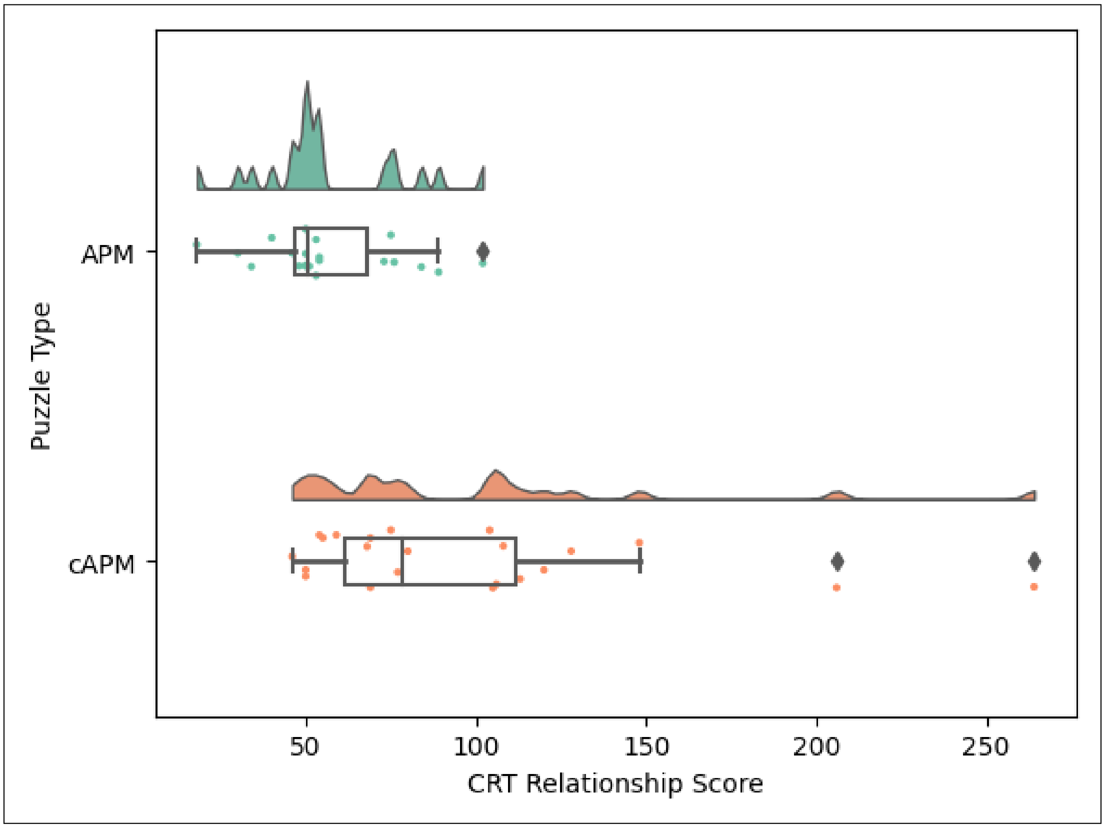


**Figure 3.5** CRT Relationship scores after solving APM and *c*APM

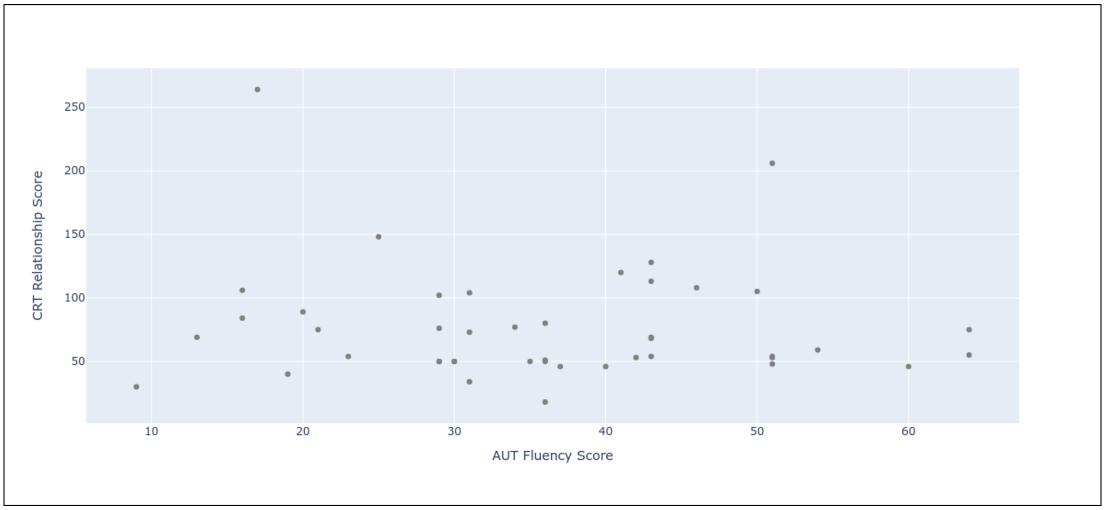


**Figure 3.6** CRT Relationship score vs AUT Fluency Score

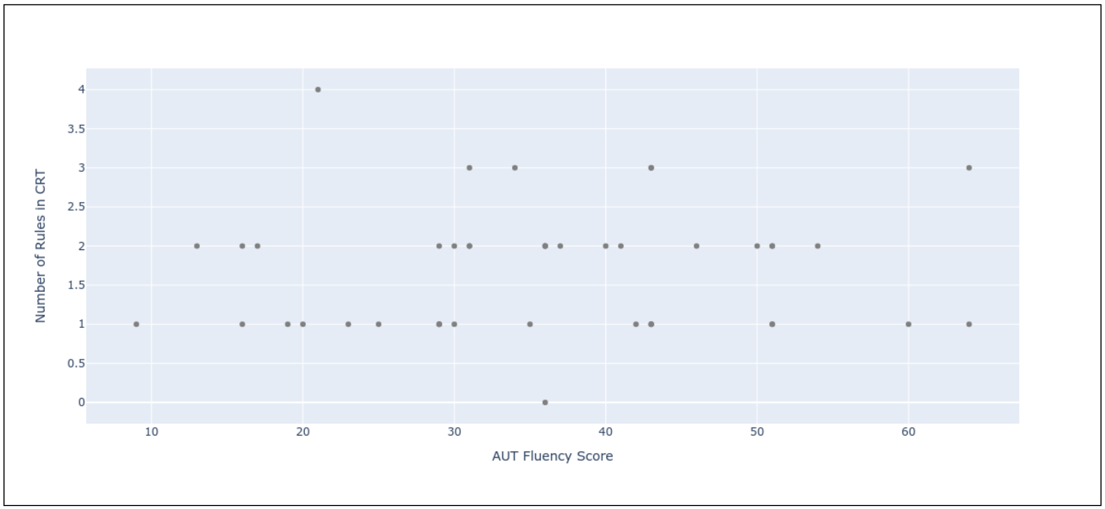


**Figure 3.7** Number of Rules in CRT vs AUT Fluency Score

induced. Therefore it is expected that *c*APM group performs better in both the ill-defined tasks compared the APM group.

We observed a significant effect of the variant of APM on CRT performance. Higher number of rules in the CRT was observed when it was preceded by *c*APM compared to the classic APM. Further, we observed a higher CRT Relationship Score under *c*APM compared to the classic APM puzzle. However, the variant of APM did not show a significant effect on AUT, fluency and elaboration scores. The transfer of creativity from one knowledge domain to another is a complex and debated topic in the field of cognitive science and creativity research. There are several challenges and limitations to consider when discussing the potential for such transfer. One such important and difficult aspect to understand the is the domain-specificity of creativity. The most difficult aspect of comprehending the domain—generality versus specificity is grasping the notion of a domain in the first place [78]. Domains can be defined in several ways, depending on how particular or general they are. Is biology a domain, or science, or life sciences, or natural sciences? In our study, the knowledge domain of the well-defined problem-solving tasks i.e APM and *c*APM consists of the following elements.

**Geometric Shapes**: The APM primarily uses geometric shapes such as squares, triangles, circles, and other abstract forms. These shapes are manipulated and combined in various ways to create patterns and sequences.

**Pattern Recognition**: Test-takers are required to recognize patterns and relationships within the visual stimuli presented to them. This includes identifying how shapes change or transform from one frame to the next.

**Rule Abstraction**: A critical component of the APM is the ability to deduce and apply rules governing the transformations of shapes. For instance, a rule might involve the rotation of a shape by a specific angle, or the addition or subtraction of elements within a pattern.

**Abstract Reasoning**: The APM assesses an individual's abstract reasoning abilities. Test-takers must use logical thinking and problem-solving skills to discern the underlying principles and rules that govern the patterns.

**Inference and Deduction**: Beyond recognizing patterns and rules, the APM also measures the capacity to make inferences and deductions based on the presented visual information. Test-takers need to predict the next step in a sequence or identify a missing element.

**Progressive Complexity**: The APM is called "progressive" because the patterns become increasingly complex as the test progresses. This progression challenges individuals to adapt their thinking to more intricate visual relationships and rules.

The CRT also shares the same knowledge domain as mentioned above. The knowledge domain of the Alternative Uses Task(AUT) involves divergent thinking, the exploration of multiple and unconventional uses for common objects or concepts, fluency, originality, flexibility, and the assessment of psychological creativity. The task is designed to evaluate an individual's creative thinking abilities and is commonly used in psychology and creativity research.

The cognitive overlap between both the knowledge domains is very minimal. This is one of the aspect why a better performance is seen in CRT and not in AUT. The variants of APM and CRT both share cognitive elements related to abstract reasoning, pattern recognition, and rule abstraction. Solving APM puzzles hones these skills, making the transition to CRT more seamless. In CRT, individuals are often required to generate creative solutions by recognizing patterns and relationships within abstract information, which aligns with the cognitive skills exercised in variants of APM. Since solving *c*APM puzzles required the juggling between convergent and divergent thinking, it helped in a better performance of CRT compared to APM group. Whereas in AUT, the overlap is not present. Also, AUT places a stronger emphasis on divergent thinking, which involves generating a wide range of possible uses for an object or coming up with numerous creative responses. This requires a different cognitive approach than CRT, which may involve generating a single creative solution based on abstract patterns or rules.

Momentum can also play a huge role here. After solving APM variants puzzles, individuals are already in a mindset that involves abstract thinking and the ability to identify novel and creative solutions. CRT typically involves more abstract or symbolic reasoning tasks, where participants may need to find creative connections or see unconventional relationships within visual or conceptual information.

The current result suggests that creativity is more domain-specific than general, especially when it is about reasoning. Further, it supports previous findings [58] that show a positive correlation between SPM scores and CRT reasoning scores. In contrast, CRT creative component scores showed a positive correlation with the Test of Creative Thinking and Drawing Production (TCT-DP). However, the caveat could be discussed when the CRT creative component is analyzed along with the features of AUT task performance by evaluating the abstraction, action, and object properties.

*Chapter 4*

# Development of Interface for the cAPM Project

The tests used in our current study, APM, *c*APM and CRT can be performed using pen and paper. But by doing so, we can only see the final output of the participants, not the thinking process behind it. The main reason for development of the interface and making these tests perform online is to capture the thought process of each individual. This becomes even more useful for *c*APM because there exists multiple solutions for each puzzle.

## 4.1 Advantages of Web based test over pen and paper

### 4.1.1 Comprehensive Detail Tracking

Web-based tests allow for comprehensive tracking of every detail throughout the testing process. Each participant's responses, completion times for each item, and any pauses taken can be automatically recorded and stored. Unlike paper-based tests where the tracking of such details relies on manual notation and later transcription, web-based platforms offer real-time data collection. This level of detail provides valuable insights into participants' cognitive processes and helps researchers gain a deeper understanding of individual test-taking behaviors. Moreover, web-based platforms can record additional information beyond mere responses. Data such as mouse movements, click patterns, and navigation choices can be logged, shedding light on the decision-making process and strategies employed by participants. This information is often lost in paper-based testing and can greatly enrich the analysis of cognitive performance.

### 4.1.2 Real-time Monitoring and Insights

Web based test enables real-time monitoring and immediate insights into test takers' progress. Unlike traditional paper tests where participants are left to their own devices and the results are analyzed post hoc, web-based platforms can provide instant feedback on participants' performance. Researchers can observe the progression of individuals through the test in real time, identifying patterns or trends that might otherwise go unnoticed.

Furthermore, real-time monitoring allows for the identification of anomalies or outliers in real time. If a participant exhibits unusual behavior or encounters technical difficulties, researchers can intervene promptly, minimizing the impact on the data quality and participant experience. Such responsiveness contributes to a more controlled testing environment and enhances the overall validity of the results.

### 4.1.3 Improved Standardization and Accuracy

Web-based Raven's Matrices testing enhances standardization and accuracy in multiple ways. By eliminating the need for manual recording and transcription, the risk of human error is significantly reduced. This ensures that the collected data is more reliable and consistent, enhancing the overall quality of the assessment.

### 4.1.4 Remote Accessibility and Reach

Conducting Raven's Matrices tests on the web offers the advantage of remote accessibility and an expanded reach. Participants from diverse geographical locations can access the test without the need to travel to a specific testing center. This broader reach enhances the diversity of the participant pool and increases the generalizability of the test results.

Moreover, the accessibility of web-based tests makes it possible to include participants who might face physical or logistical barriers to attending a traditional testing session. Individuals with disabilities or those with busy schedules can participate more easily, promoting inclusivity and diversity in the sample.

### 4.1.5 Advanced Data Analysis

Web-based Raven's Matrices tests provide a wealth of data that can be subjected to advanced data analysis techniques. The digital nature of the platform allows for seamless integration with data analysis tools, enabling researchers to conduct intricate analyses of response patterns, completion times, and more. Machine learning algorithms can be applied to uncover hidden patterns and correlations, contributing to a deeper understanding of cognitive abilities and test performance. The data collected from web-based tests can also be used to generate visualizations that aid in the interpretation of results. Interactive graphs and charts can provide insights into participant performance trends and highlight areas of strength or weakness.

## 4.2 Logs

We collected 2 types of logs from the study. The test environment for CRT was also ready, but we haven't used it because we thought participants would find it difficult to draw on screen using mouse compared to pen and paper.

### 4.2.1 User Logs

#### 4.2.1.1 Browser Details

- broswer_name
- navigator_appVersion
- screen_height
- screen_width

#### 4.2.1.2 IP Details

- city
- countryCode
- countryName
- ipAddress

#### 4.2.1.3 APM Type

- apm_type (A or T)

#### 4.2.1.4 Demographic Details

- age
- chosenStream
- creativityLAQ
- gender
- handedness
- otherGender
- year

#### 4.2.1.5 Feedback

- effort
- frustrationLevel
- mentalDemand
- performance
- physicalDemand
- temporalDemand
- uiDistraction
- additionalFeedback
- upi

### 4.2.2 Puzzle Logs

#### 4.2.2.1 Overview

- actionType
- parameters
- position
- timestamp
- uid

#### 4.2.2.2 Logs of actionType

- pickupPuzzle
- dropOption
- pageChange
- startPuzzle
- endPuzzle
- optionSelect_T

#### 4.2.2.3 Logs of parameters

- puzzleType
- from
- to
- optionId
- nextLocation

#### 4.2.2.4 Values of logs of position

- /start/
- /start/details/
- /start/consent/
- /start/guidelines/
- /demographic/instructions/
- /demographic/task/
- /task/start/
- /task/introduction/
- /task/example/
- /task/example/2
- /task/instruction/
- /task/puzzle/1
- /task/end
- /crt/start
- /crt/instruction
- /crt/task
- /crt/end
- /feedback/start

- /feedback/task
- /thankyou

## 4.3 Technical Details

- **Frontend**: ReactJs, Bootstrap
- **Backend**: NodeJs
- **Database**: Firestore Database
- **Hosting**: Firestore Hosting

## *Chapter 5*

# Summary and Future Directions

## 5.1 Summary of Key Findings

We investigated the impact of constraints in solving Advanced Progressive Matrices (APM) puzzles on the creation of APM-like puzzles. The findings revealed that individuals who solved APM puzzles under lesser constraint conditions, produced APM-like puzzles that were more challenging and required higher levels of abstract reasoning to solve. This suggests that the constraints imposed during problem-solving can influence the characteristics of the problems individuals create, potentially making them more conducive to creative thinking. Following the previous study, we explored the transfer of creativity induction from one knowledge domain to another. So we added an additional creativity task namely Alternative Uses Task (AUT). The current findings revealed that the constraints haven't significantly impacted the performance of AUT and creativity is more domain-specific than domain-general.

## 5.2 Future Directions

The research conducted in this thesis has shed light on the relationship between constraints and creative reasoning in problem-solving. However, several avenues for future research remain unexplored, and here are some potential directions:

**Diversity of Constraints**: Investigate a wider variety of constraints, both in terms of nature and severity. For example, constraints related to cultural differences, and group dynamics could be explored to understand their unique effects on creative reasoning.

**Individual Differences**: Investigate how individual differences, such as personality traits and cognitive styles, interact with constraints to affect creative reasoning. Understanding how these factors modulate the relationship can lead to personalized approaches for enhancing creativity.

**Long-Term Impact**: Examine the long-term impact of constraints on creative thinking. Do constraints in problem-solving have lasting effects on an individual's creative abilities, or are they more short-term influences?

**Neuroscientific Studies**: Conduct neuroscientific studies to uncover the neural mechanisms underlying the interplay between constraints and creative reasoning. Understanding the neural basis of this relationship can provide deeper insights into the cognitive processes involved.

**Real-World Applications**: Explore the application of findings to real-world scenarios, such as innovative problem-solving in organizations, curriculum development in education, and creative thinking in artistic endeavors.

In conclusion, the relationship between constraints and creative reasoning in problem-solving is a complex and multifaceted area of study. The research presented in this thesis has provided valuable insights into this relationship, but there is still much more to explore. Understanding how constraints can be leveraged to enhance creative thinking is not only academically intriguing but also has practical implications for fostering innovation and problem-solving in various domains of human endeavor.

## 5.3 Defense reviews

### 5.3.1 Experiment Design

**Point 1**: Rebuttal is inadequate for this point - Examiner: Also, the thesis should discuss alternative explanations (e.g. priming) to what may have given rise to differences in the behaviour observed - what is the way to overcome this limitation?

We thank the reviewer for raising concerns regarding alternative explanations e.g. priming or individual differences and the ways to overcome this limitation. We will first discuss the possibility of individual differences and ways to address the issue followed by the discussion about the priming as an alternative explanation.

a. In the current study, to address the individual differences as a possible alternative explanation, a pre-reasoning ability test could have been administered to establish an individual baseline for reasoning ability or/and creative abilities. In this design, participants must have been assessed on similar abstract reasoning and other creativity tasks to compare their reasoning and creative thinking ability regardless of the experimental conditions, i.e., the two types of abstract Raven's Matrices reasoning conditions: APM and *c*APM, followed by CRT testing. Alhough our study is limited in establishing the individual baselines, we attempted to mitigate the plausibility of alternative explanations through a robust experimental design by employing random assignment techniques.

We used the simple randomization technique, odd/even, to allocate participants to the two conditions, APM and cAPM. The random assignment technique provided an equal chance for participation in both experimental conditions. The randomization helped us to avoid any form of selection bias as we recruited participants via social media, email, and snowball methods. In other words, the randomization technique allowed us to reduce the chances of threat caused by group differences (or individual differences) in any systematic way because each participant got an equal chance to participate in the given experimental conditions.

Further, as per the examiner's recommendation, we conducted a permutation test to assess the significance of the observed effect. We observed a significant effect of constraints on the creative reasoning task suggesting that the manipulation, *c*APM, helped inducing the creative thinking.

b. Regarding priming as an alternative explanation, we will begin the evaluation by first describing the associated strategies involved in solving and creating APM puzzles and then evaluating the possibility of priming as an alternative explanation.

In the current study, the two experimental groups were asked to first solve either traditional APM or creative APM (*c*APM) and then create the Raven's like puzzle with an answer. We used traditional APM as a control group, which is used in previous studies [56, 57] as a precursor to create a Raven's like puzzle using CRT task. Both APM and CRT, though involves reasoning either in solving and creating task respectively, operates in two different problem spaces. The reasoning involved in APM is performed within the well-structured problem space with fixed sets of determinants to solve the problem. Such problems demand more convergent thinking, which entails interpretation and deduction of the rules and relationship between items/ component in order to complete the puzzle. However, the CRT demands operations in ill-structured problem space without any fixed set of determinants and fixed response. In CRT, participants begin the task with multiple optons, using divergent thinking and converge to the construct the rules and relationship between items, using convergent thinking. CRT is one of the creative thinking tasks, which involves both the divergent and convergent thinking to complete the task. Give that the two problems, APM puzzle solving and APM puzzle generation, operate in two different problem spaces despite a common knowledge domain, it was difficult to a., understand the relationship between the two tasks- puzzle solving and puzzle generation, and b. induce/ stimulate creativity. We created *c*APM to bridge these gaps. *C*APM enabled us to stimulate divergent thinking in a standardized puzzle solving task, with a fixed expected response. Though the end results might have been same the process to achieve the end result was different.

In other words, although, both the APM and cAPM tasks are closed-ended abstract reasoning tasks, the cognitive strategies required to approach the two problems are different. For the traditional APM solving participants were expected to recruit primarily convergent thinking to arrive at a correct solution for the last cell. Whereas, in *c*APM, participants are needed to think divergently (looking for more options) than deducing the rules and finally completing the missing piece in traditional APM. In both cases, i.e., APM and cAPM, the convergent thinking enabled them to complete the puzzle correctly. However, in *c*APM the divergent thinking helped them exercise the method required to complete CRT effectively. Just by varying the constraints for the close-ended tasks, we were able to induce the cognitive strategies required to perform the creative reasoning task, and observed its effect on CRT performance.

Most importantly, the convergent and divergent thinking are associated with biased cognitive processing, namely, persistence and cognitive flexibility, respectively. In literature, the two thinking styles have been studied separately, using the remote association test (RAT) relying heavily on convergent thinking as it demands one correct answer, and Guilford's alternative uses task (AUT) relying heavily on divergent thinking as it demands remotely associated concepts, allowing multiple optimal solutions [127]. The flexibility allows one to think about the multiple views/ options associated with strong activation in the inferior frontal gyrus, whereas the persistence enables more focused thinking and helps arrive at one solution, which is expected to be associated with the dorsolateral prefrontal cortex (DLPFC) and temporal-parietal network. The *c*APM enables recruiting both, yet converging to demand a correct solution, and therefore, helped participants think for the open-ended CRT better than when the traditional APM preceded it.

Given the complexity of the APM and *c*APM tasks, it demanded more than the remote association or memory to complete CRT task effectively. The nature of the puzzle solving and puzzle creating task does not support the possibility of alternative explanation as priming effect. In case of priming, it involves presenting a stimulus intended to unconsciously introduce a concept into working memory, which then influences later behavior [28, 104]. It has been argued that when individuals encounter specific information, it triggers corresponding changes in their behavior based on the associated mental representation. Though, studies have used priming cues/ stimulus to influence abstract concept thinking, like, counterfactual [40], stereotype [100], deliberative versus implemental thinking [44], individualistic versus collectivistic norms [12], or achievement (Dennis et al., 2013), the results from these studies have been mixed [104], with some results reported at the cost of replication. It has been argued that priming has a weak and transitory effect. It has successfully worked with a specific stimulus, like word priming experiments, and often involves influencing perceptual processing. A task like creative reasoning may demand longer engagement than the transitory priming effect. Priming effects are often immediate and can influence behavior or perception shortly after exposure to the priming stimulus. However, the lasting duration of the priming effect is still unclear [101].

Recently, a study has shown that creativity can be primed/ induced and can be enhanced through certain activities. However, the priming condition differed from the previous traditional priming method. In this study, participants were divided into 4 groups where each group had to solve a puzzle/game followed by a creativity task. In condition 1, a simple digital puzzle game that contains many solutions (divergent thinking condition). In the second condition, participants had to solve a short game that had a single fitting solution (convergent thinking condition). In condition 3, participants had to solve mathematical problems. The fourth condition was a passive control condition. Following these four types of tasks, participants were asked to perform the Torrance Test of Creative Thinking (TTCT) [48]. The results showed enhanced creativity for the games that allowed multiple options entailing divergent thinking tasks, compared to the mathematical problems that involved primarily convergent thinking[48].

The above study showed that the type of task performed before creativity task impacts the performance of creative task. In our study as well, we observed the creativity task performance was impacted by the type of problem solved. However, the current study is different than priming studies, in which the concepts or stimulus was presented either subliminally or by probing a particular construct, like *professor vs soccer hooligan*. An important observation for both these studies is that the creativity task is conducted immediately after the initial condition. This leads to an important discussion on the duration of the impact, i.e., ”how long does the impact of constraints last? Is it just for the short term or can it affect long term as well?” For future research, we can introduce a time interval varying from immediate to a week time, and investigates the effect of type of problem solving on problem generation task (CRT) performance, and would enable a better assessment of the independent effects of problem-solving constraints on subsequent creative thinking. The study could be expanded to investigate the role of domain knowledge in creative thinking.

### 5.3.2 Statistical Analysis Updates

**Point 2:** Some of the statistical comparisons between groups were not valid as pointed out in the defense. These could be mentioned ta the end as well.

**Response:**

The reviewer suggested to perform a permutation test to assess the significance of the results. For both the study 1 and 2, we conducted permutation test for the CRT results and found the result to be statistically significant. For the second study, there was an error in defense slide presentation which mistakenly reported Pearson correlation coefficient instead of effect size for the AUT results(Slide 32, 33). Below are the corrected response against statistical reporting.

### 5.3.3 Statistical Analysis update for study 1

#### 5.3.3.1 Number of Rules in CRT

The Shapiro-Wilk test for both groups indicated violation of normalcy for CRT scores, $c$APM (W = 0.88, $p = 0.014$) and APM (W = 0.73, $p < 0.001$), and led us to choose non-parametric analysis. Mann-Whitney U test showed significant effect of varying constraints in APM puzzle (i.e., APM with high constraints and $c$APM with lesser constraint) on the number of rules used in CRT with medium standardized effect size (U = 125.0, $p = 0.002$, $r = 0.46$). Participants used more number of rules in CRT when they solved APM with lesser constraints of rules, i.e., *c*APM (*Median*=2) than traditional APM (*Median*=1) (Figure 2.7). We conducted a permutation test with 10000 samples and found the result to be statistically significant($p = 0.002$) (Figure 5.1).

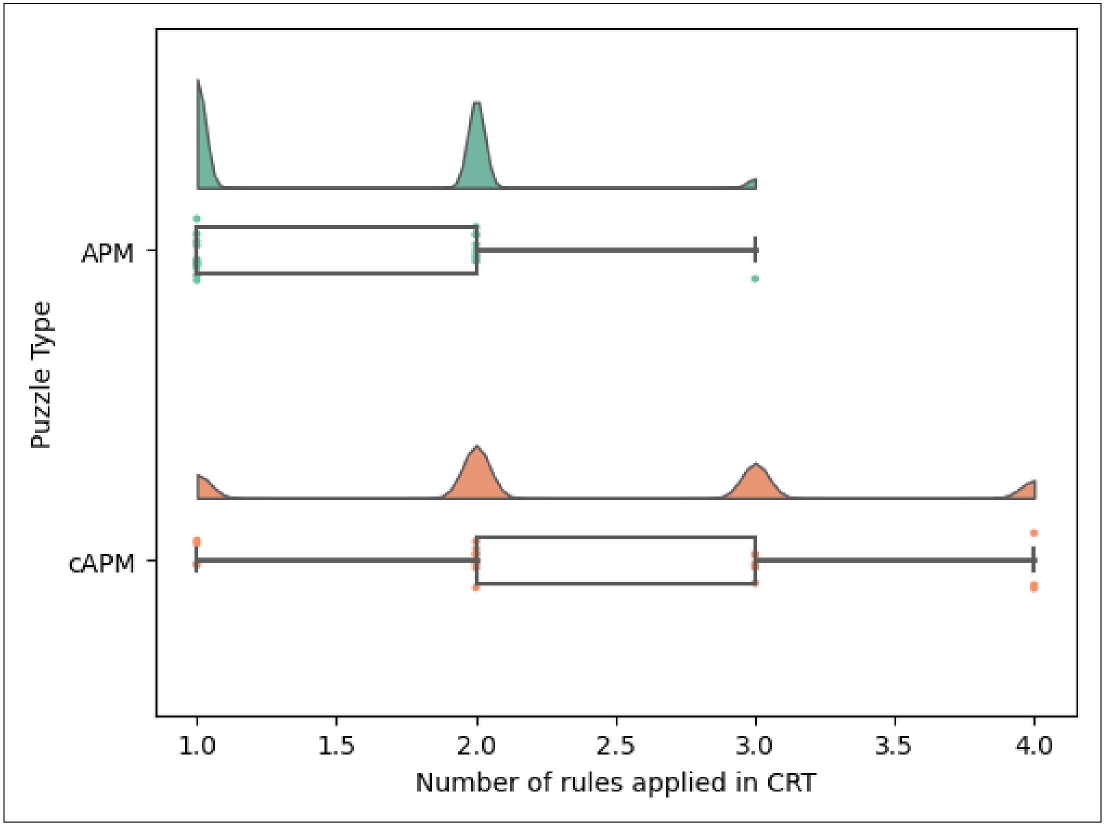


**Figure 5.1** Number of rules applied in CRT after solving *c*APM and APM

#### 5.3.3.2 CRT Relationship Score

We observed a significant violation of normalcy for CRT relationship score for both groups, *c*APM (W = 0.79, $p < 0.001$) and APM (W = 0.87, $p = 0.006$) and therefore performed non parametric analysis. The *c*APM group showed a significantly higher CRT relationship score (*Median* = 79.25) than APM (*Median* = 53.00) with a medium standardized effect size (U = 141.5, $p = 0.011$, $r = 0.38$) (Figure 2.8). We conducted a permutation test with 10000 samples and found the result to be statistically significant($p = 0.0118$) (Figure 5.2).

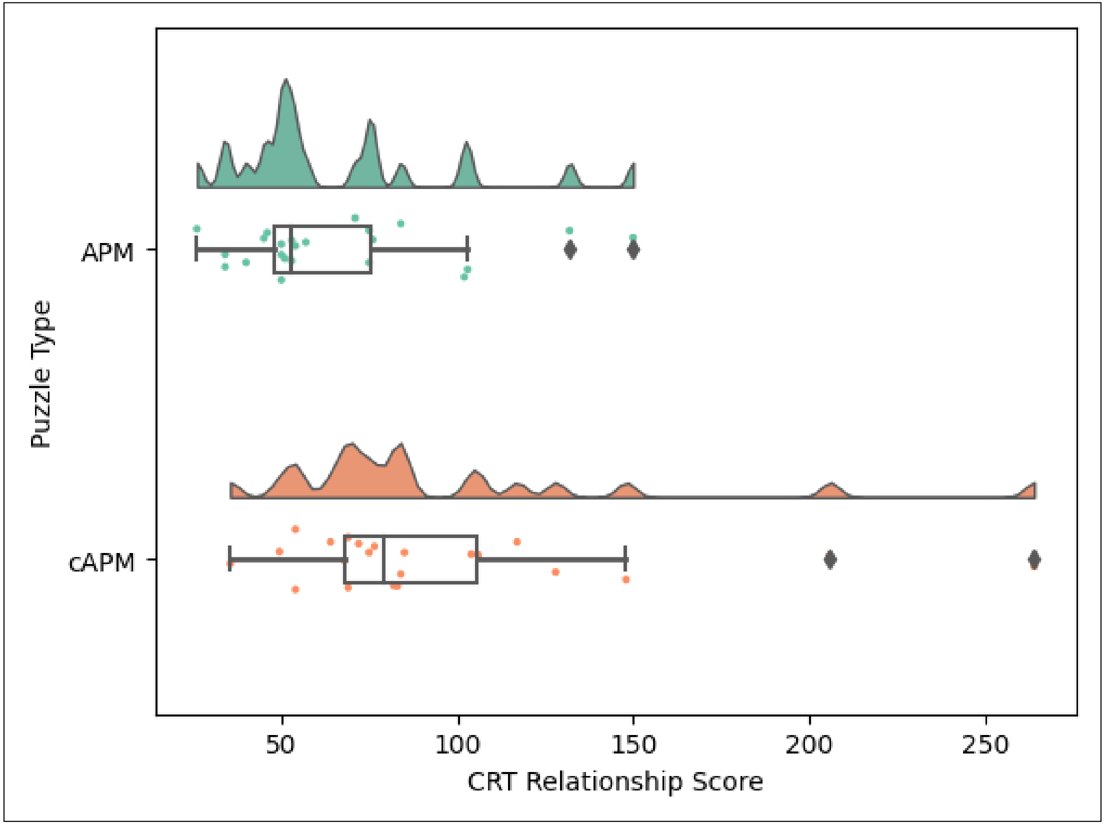


**Figure 5.2** CRT Relationship scores after solving *c*APM and APM.

### 5.3.4 Statistical Analysis update for study 2

#### 5.3.4.1 CRT Performance

#### 5.3.4.2 Number of Rules in CRT

The Shapiro-Wilk test revealed that both groups had deviations from normality in their number of rules in CRT, with *c*APM (W = 0.84, $p = 0.003$) and APM (W = 0.70, $p < 0.001$). The Mann-Whitney U test revealed a statistically significant impact of different constraints in the APM puzzle on the number of rules utilized in the CRT. The standardized effect size was found to be medium (U = 394.0, $p < 0.001$, $r = 0.58$). The participants demonstrated a higher number of rules in the CRT when they solved *c*APM($Median = 2$) compared to the traditional APM($Median = 1$). We conducted a permutation test with 10000 samples and found the result to be statistically significant($p < 0.001$) (Figure 5.3).

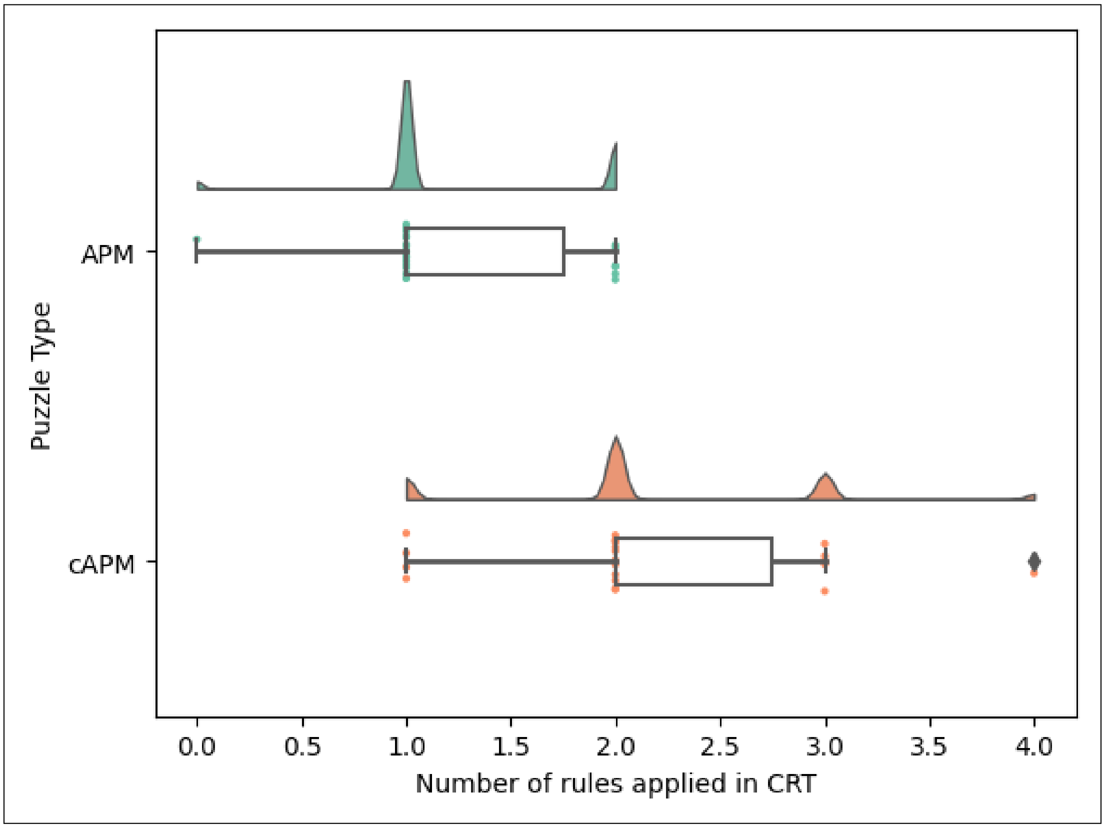


**Figure 5.3** Number of rules applied in CRT after solving APM and *c*APM

#### 5.3.4.3 CRT Relationship Score

The Shapiro-Wilk test for the APM group(W = 0.92, $p = 0.11$) was performed and did not show evidence of non-normality. The Shapiro-Wilk test revealed that the *c*APM group (W = 0.81, $p = 0.0007$) had deviated from normality. The Mann-Whitney U test revealed a statistically significant impact of different constraints in the APM puzzle on the CRT Relationship Score. The standardized effect size was found to be large (U = 393.5, $p < 0.001$, $r = 0.54$). The participants demonstrated a higher CRT Relationship Score when they solved *c*APM(*Median* = 78.5) compared to the traditional APM (*Median* = 50.5). We conducted a permutation test with 10000 samples and found the result to be statistically significant($p < 0.001$) (Figure 5.4).

#### 5.3.4.4 AUT Fluency Score

The fluency score for both groups, APM(W = 0.97, $p = 0.71$) and *c*APM(W = 0.96, $p = 0.66$) didn't violate the normality assumptions. An independent t-test was performed between both groups and no significant difference was observed($p = 0.80$) with a small effect size($d = 0.074$). (Figure 5.3).

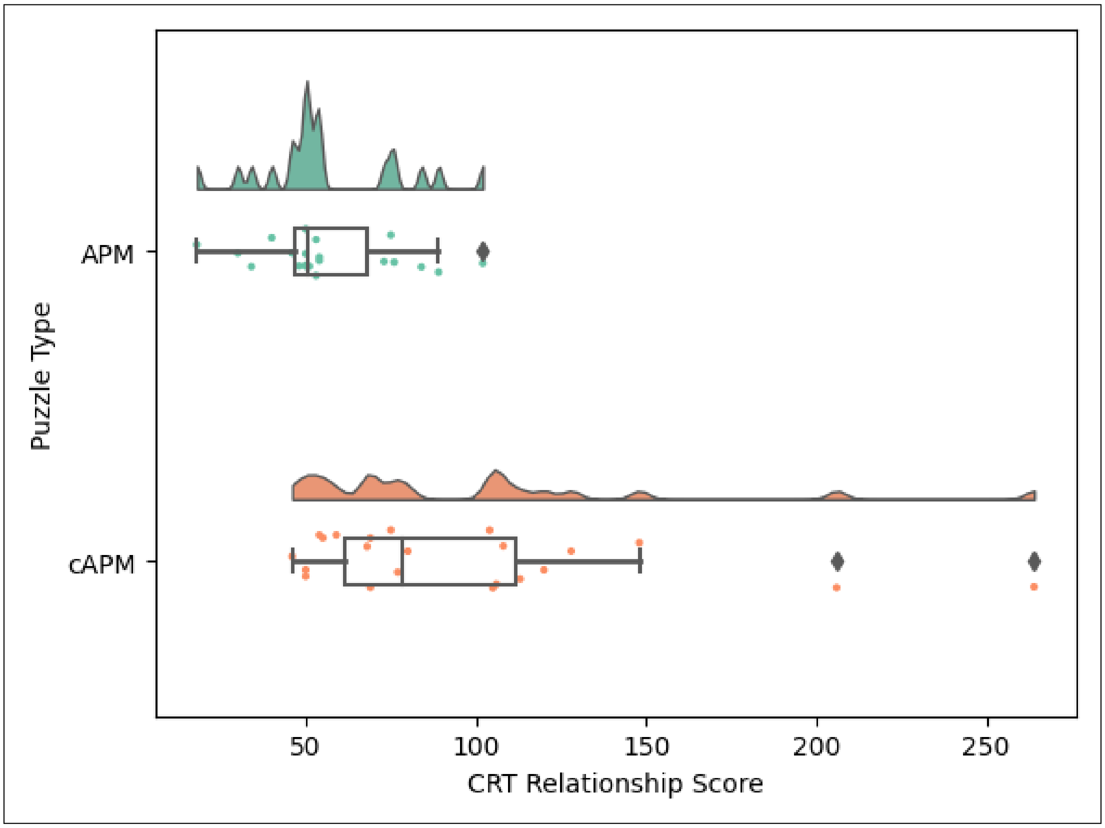


**Figure 5.4** CRT Relationship scores after solving APM and *c*APM

#### 5.3.4.5 AUT Elaboration Score

The elaboration score was calculated as the summation of the number of words in each use case for all use cases. The Shapiro-Wilk test revealed that both groups had deviations from normality in their elaboration scores, with *c*APM (W = 0.88, $p = 0.015$) and APM (W = 0.90, $p = 0.04$). The Mann-Whitney U test revealed no statistically significant impact of different constraints in the APM puzzle on the Elaboration Score. The observed effect size is small ($p = 0.48$, $r = 0.11$) (Figure 5.4).

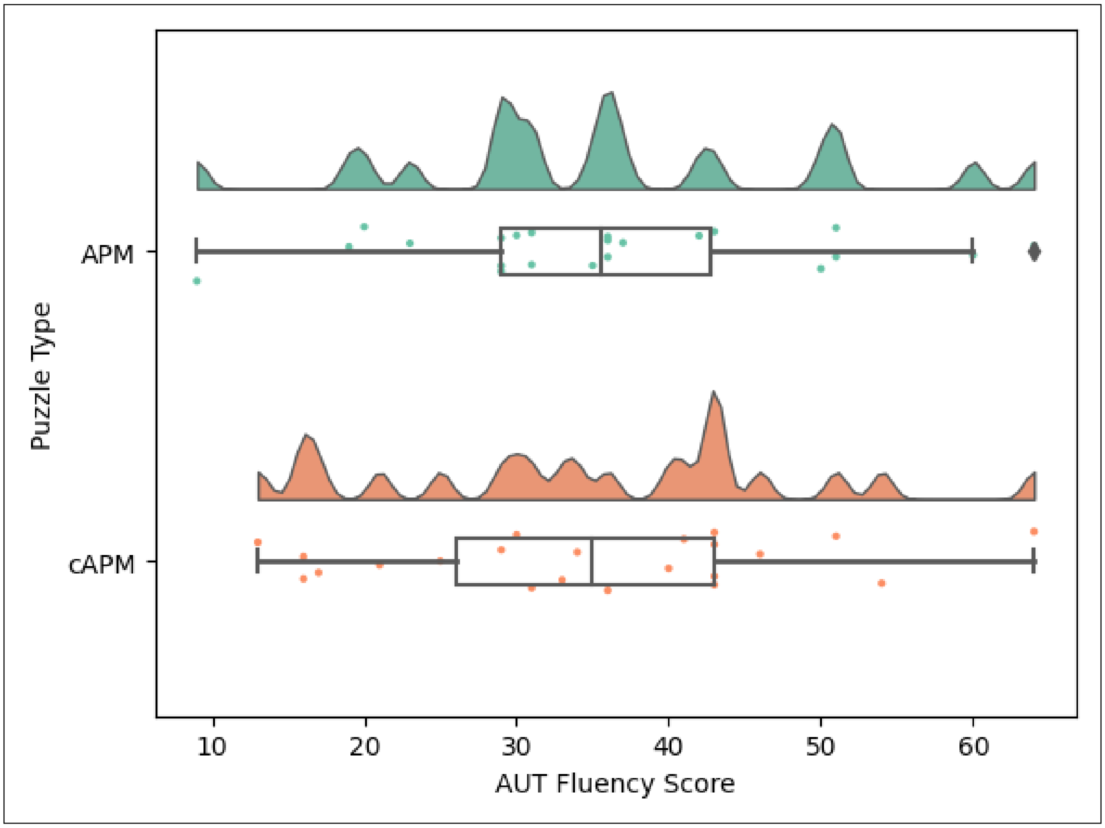


**Figure 5.5** AUT Fluency score b/w APM and *c*APM

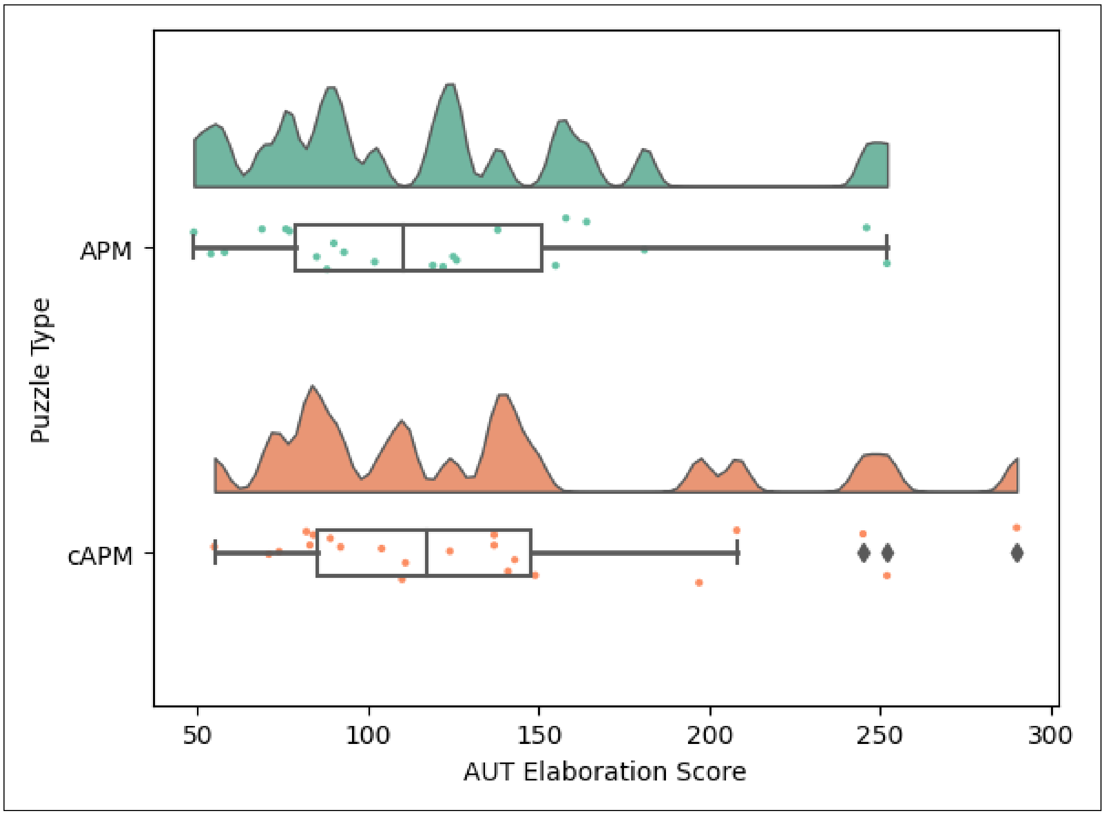


**Figure 5.6** AUT Elaboration score b/w APM and *c*APM

# Related Publication and Presentations

1. N. Arcot, P. Srivastava, S. Jaarsveld, et al. Do constraints in apm solving affect apm-like puzzle creation? In Proceedings of the Annual Meeting of the Cognitive Science Society, volume 45, 2023.
2. N. Arcot, P. Srivastava. Can induction of creativity from a knowledge domain be transferred to a different knowledge domain? Accepted for Oral Presentation at The 10th edition of the Annual Conference of Cognitive Science is being hosted at IIT Kanpur from 9th-11th December, 2023
3. N. Arcot, P. Srivastava, S. Jaarsveld, et al. Breaking Domain Barriers: An Inquiry into the Transfer of Induced Creativity (submitted in CSS 2024)

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