

The relationship between analogical problem solving and analogical reasoning

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Declaration

I hereby declare that this thesis is my own unaided work.

It is being submitted for the degree of Doctor of Philosophy at the Faculty of Humanities, University of the Witwatersrand, Johannesburg.

It has not been submitted previously for this or any other degree or for examination at this or any other university.

N. Israel

_____ July 2019

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All opinions, findings, conclusions, and recommendations expressed in this report are those of the author and the NRF has no liability in this regard whatsoever

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Abstract

Analogical problem solving occurs when a previously acquired source solution strategy is retrieved and applied to an isomorphic target problem based on shared structural correspondences. In addition to being seen as an effective and frequently implemented heuristic strategy, it also plays a vital role in facilitating creative thinking and learning and is widely utilised as a key instructional mechanism in a range of teaching contexts. Despite its clear importance, empirical evidence regarding the links between analogical problem solving and a range of other factors, including those located within the individual problem solver, remains limited. This includes the nature of the associations between analogical problem solving as a heuristic strategy and other forms of reasoning using analogy. As such, there is a need for further research that serves to clarify and extend conceptual understandings of these relationships and to identify predictive patterns; this could contribute meaningfully to both theory development and application. The focus of the current study was thus to explore the associative and predictive links between analogical problem solving and different forms of analogical reasoning in the South African context. More specifically, the study examined solution rates for two different forms of analogical problem solving (directed and open analogical transfer) as well as the associations between these and verbal and non-verbal analogical reasoning, heuristic strategy preference (including preference for an analogical approach), and several demographic variables (gender, home language, type of schooling, and socioeconomic status). Predictive models with each form of analogical transfer as the outcome variable were also created. The design of the study was quantitative, non-experimental, correlational, and cross-sectional, and the data was collected using a series of tasks and self-report measures designed to capture the constructs of interest. Following piloting, a final sample of six-hundred and fifty-eight undergraduate university students was obtained for the main study. Statistical analyses were used to address the research questions; these included one-way ANOVAs, t-tests, Chi-squared tests of association, and logistic regression. The results obtained from the analyses suggested that rates of analogical transfer in the South African context were slightly lower than those typically observed internationally; a significant and positive relationship between the two forms of analogical transfer assessed in the study was also identified. Analogical problem solving was found to be significantly, positively, and weakly associated with analogical reasoning, and was unrelated to a preference for utilising analogy as a heuristic strategy. A number of important distinctions in analogical transfer performance on the basis of the various demographic variables were also identified. Taken together, these findings provide a unique and novel set of insights into the phenomenon of analogical problem solving; their implications augment existing theory and serve as a base for innovative future work in the field.

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Chapter 1: Introduction

Problems occur when a desired goal or outcome is obstructed, and their solution constitutes one of the most fundamental higher order cognitive activities engaged in by human beings (Condell et al., 2010; Dunbar, 1998; Holyoak, 1995; Jonassen, 2000; Wang & Chiew, 2010). Skilled problem solving is regarded as a key component of both intelligent and creative behaviour and as a measure of authentic learning. Furthermore, the development of problem solving schemas, which capture content and procedural knowledge relevant to the resolution of a particular category of problem, underpins much of the educational enterprise as well as everyday occupational and social functioning (Billing, 2007; Chi & Glaser, 1985; Holyoak, 1995; Jonassen, 2000; 2010; Kahney, 1993; Ohlsson, 2012). Advancing understandings of the ways in which problem solving capacity can be enhanced is thus a critical exercise that could contribute substantively to improved human performance.

When faced with a novel problem, there are a number of potential heuristic strategies individuals can employ – these represent ways in which to approach resolving the problem that assist the individual but do not guarantee an ideal outcome (Chen & Siegler, 2013; Gick, 1986; Lee, 1992; Wang & Chiew, 2010). Of these, analogy, “...*the process of understanding a new experience in terms of a well understood previous experience*” (Thomas, 2008, p. 248), is often identified as the most frequently applied and most effective approach (Antonietti, Ignazi, & Perego, 2000; Güss & Wiley, 2007). Analogical problem solving “...*occurs when specific, structural correspondences between objects and relations in the source and target are used to adapt the solution procedure learned for the source into an analogous procedure for solving the target*” (Novick & Holyoak, 1991, p. 400), in other words, it refers to a process whereby a known, previously encoded solution strategy to a problem recognised as being structurally isomorphic is retrieved and adapted to solve the current problem faced (Gentner & Smith, 2012; 2013; Gick & Holyoak, 1980; 1983; Holyoak, 2012; Neuman & Schwarz, 1998; Reeves & Weisberg, 1994; Reimann & Schult, 1996). The ability to implement analogy as a heuristic approach is widely recognised as a vital skill with relevance to multiple areas of human activity, including occupational functioning and education (Antonietti, 1996; Barnett & Ceci, 2002; Forsyth, 2018; Gentner & Smith, 2012; Kaminski, Sloutsky, & Heckler, 2013). It is a core mechanism for promoting inference and facilitates the transfer of knowledge through bridging the divide between existing and novel information (Corkill & Fager, 1995; Holyoak, 2012; Thomas, 2008; Zook, 1991). It is thus a vital method of learning, as well as a catalyst for creative and intelligent thought (Chen & Siegler, 2013; Cushen, 2012; Francis, 1999; Peterson & Wissman, 2018; Reeves &

Weisberg, 1994). It is also associated with a wide range of other high-level cognitive and processing skills (Francis, 1999; Gick & Holyoak, 1980) and can be considered as “...*an essential aspect of competent performance in any complex domain*” (Billing, 2007, p.493).

Despite its clear importance, a close analysis of the existing literature reveals a number of areas in which theoretical understandings of analogical problem solving as a phenomenon are either incomplete or inconclusive. This is highlighted by the taxonomic structure proposed by Barnett and Ceci (2002), whose primary intention was to provide a means through which previous knowledge regarding transfer of learning could be categorised and missing elements illuminated. Their framework, which is equally applicable to analogical problem solving as a critical exemplar and primary component of transfer, epitomises the need for integration and expansion of existing theory. As Corkill and Fager (1995) note, “...*transfer via analogy does not happen by chance ... the mechanisms underlying successful transfer, however, are complex and somewhat elusive*” (p.182).

On this basis, further research intended to identify, clarify, or determine the nature of the relationships between analogical problem solving and a host of other factors (for example, expertise, cognitive capabilities, metacognitive capacity, personality, motivation, context, and individual differences) or the predictive capacity of the latter for the former is clearly warranted. This form of model building is not only justified in its own right, given the prominence of the phenomenon in question, but could also provide crucial insights for a range of associated skills (including intelligence, transfer of learning, and creativity). Additional empirical evidence could also not only assist with the development of more comprehensive and nuanced interpretations of analogical problem solving as a psychological construct, but could be of pragmatic value as a means through which to refine and enrich existing educational protocols and skills training (particularly as regards the use of analogy as a heuristic strategy).

To this end, the overarching intention of the current study was to provide a small yet novel set of empirical findings able to assist in clarifying and refining available conceptual interpretations of the construct of analogical problem solving, thus contributing to theoretical and practical advancement. More specifically, the study aimed to explore the nature of the relationships between rates of analogical transfer and verbal and non-verbal analogical reasoning, as well as heuristic strategy preference (including preference for analogy as a heuristic strategy), with a view to distinguishing between these concepts and highlighting the roles of the latter concepts in predicting the skilled use of analogy as a problem solving mechanism. An attempt to expand traditional empirical assessment of analogical transfer

through the use of a novel methodological approach was also implemented in the study, and thus both directed (prompted) and open forms of analogical transfer were examined. The study was conducted in a novel context (South Africa) wherein, to date, no previous research regarding analogical problem solving appears to have been carried out, and, as a secondary aim, the potential role played by several demographic factors (gender, home language, type of schooling, and socioeconomic status) in determining skilled analogical transfer was explored as well.

The study that was conducted to explore these questions was quantitative, non-experimental, correlational, and cross-sectional in nature. The data was obtained by asking participants to complete a series of tasks and self-report measures relevant to the variables under investigation – these were piloted in a sample of senior university students prior to being administered to the main sample. Six-hundred and fifty-eight undergraduate university students who volunteered to participate constituted the final sample obtained for the study. The data obtained from these participants was analysed using a series of statistical analyses that included frequencies, one-way ANOVAs, t-tests, Chi-squared tests of association, and logistic regression.

In the chapters that follow, an attempt is made to provide a comprehensive overview of the existing literature, including working definitions of the core concepts and critical summaries of relevant theoretical and empirical interpretations available to date. The review culminates in a detailed justification describing the issues that provided direct motivation for the various elements of the current study, and ends with the key research questions that framed the project as a whole. This is followed by a detailed outline of the methods enacted in the current study, an overview of the results obtained for each key research question posed, and a discussion of these findings in the context of existing work in the field. Strengths and limitations of the current study, as well as implications and directions for future research, are presented as well.

Chapter 2: Analogical problem solving

The following chapter presents a framework for understanding both the wider field of problem solving and more specifically analogical problem solving as a key heuristic strategy that is often deployed when faced with novel problems. It also provides an overview of the process and prevalence of analogical problem solving and a brief description of certain highly relevant empirical findings in the area.

2.1. Problem solving

A *problem* arises when a person has a goal or intention but lacks the knowledge, resources, means, or understanding necessary to attain that goal; problem solving can therefore generally be regarded as a process of goal-attaining behaviour (Dominowski & Bourne, 1994; Dunbar, 1998; Holyoak, 1995; Kahney, 1993). This process involves engaging a complex set of cognitive, affective, and behavioural skills in order to identify potential options available for obtaining or achieving the intended outcome; and interacts with other cognitive activities including learning, inference, abstraction, and synthesis (Condell et al., 2010; Heppner, Pretorius, Wei, Lee, & Wang, 2002; Wang & Chiew, 2010). As such, it is argued that human problem-solving lies at the heart of intelligent activity (Chi & Glaser, 1985) and represents “...one of the most important manifestations of human thinking” (Holyoak, 1995, p.267). The ability to effectively solve problems is also seen as one of the most critical desirable outcomes of the educational process (Jonassen, 2000; Kyllonen, 2018).

Problem-solving is pervasive in that problems are habitually encountered in all spheres of human life (Antonietti et al., 2000; Holyoak, 1995; Jonassen, 2000). Jonassen (2010) identifies nine different problem forms that humans typically face, namely: story problems; rule-induction problems; decision-making problems; troubleshooting problems; diagnosis-solution problems; strategic performance; policy analysis problems; design problems; and dilemmas. Of these, the first two categories (story and rule-induction) are particularly prevalent in the educational sphere; whereas the remainder typically play out in everyday practical, social, and occupational life situations (Jonassen, 2010; Kahney, 1993).

Problems can also be distinguished on the basis of the amount of information available to the solver regarding the nature of the difficulty (givens); the desired outcome (goal); and potential actions that could or could not be used to attain said outcome

(operators) (Kahney, 1993; Wang & Chiew, 2010). *Well-defined problems* are those where the parameters regarding the initial problem state, the desired goal state, operators that are permissible or legal, and operators that are not permissible (constraints) are detailed and complete; whereas *ill-defined problems* are those where these same parameters are incomplete or lack critical information (Condell et al., 2010; Dunbar, 1998; Holyoak, 1995; Pretz, Naples, & Sternberg, 2003). Ill-defined problems, although more realistic and representative of the typical problems faced by individuals on a daily basis, are also more difficult to clarify, divide, and track in terms of the solution process; and are thus both less well understood and less researched than well-defined problems within the available literature (Chi & Glaser, 1985; Metallidou & Platsidou, 2008; Pretz et al., 2003).

Regardless of the type of problem faced, reaching a solution is typically perceived to involve a sequence of transformations allowing movement from the initial state to reach the desired goal or outcome (Dunbar, 1998; Holyoak, 1995; Ohlsson, 2012). This solution process involves consciously or subconsciously working through a set of relatively standardised steps, namely: recognition of the problem, goal definition, and mental representation (also termed information extraction); development of an initial solution strategy, organisation of knowledge, prediction of further developments, and allocation of resources (all encompassed within searching); and decision-making, monitoring progress, interim evaluation, and evaluation of the final outcome (all subsumed under implementation) (Antonietti et al., 2000; Gick, 1986; Güss & Wiley, 2007; Pretz et al., 2003). These steps or stages are potentially iterative, non-sequential, and vary in importance depending on the nature of the problem faced; flexibility is required throughout the process (Güss & Wiley, 2007; Pretz et al., 2003).

Research suggests that successfully working through the various stages and reaching an optimal problem solution is dependent on many factors. These include: the level of difficulty of the problem and the domain within which it is situated; the extent to which the solver is familiar with both general problem-solving methods and with the specific relevant domain (including level of expertise); cognitive capacity (including intellectual ability, working memory, and analytical and divergent thinking capabilities); metacognitive capacity (including executive planning, self-regulation, evaluation, self-efficacy, and reflection); personality characteristics and degree of motivation; and contextual factors (including language, culture, and environment) (Antonietti et al., 2000; Billing, 2007; Cho, 2010; Condell et al., 2010; Gick, 1986; Jonassen, 2000; Kahney, 1993; Mayer, 1998; Pretz et al., 2003). Successful problem solving over time is also dependent on the extent to which the individual is able to benefit from having solved similar problem types in the past and improve

their performance – a phenomenon termed *positive transfer* (Day & Goldstone, 2012; Kahney, 1993; Pretz et al., 2003). In contrast, *negative transfer* occurs when prior knowledge or experience inhibits problem solving, interferes with the solution sequence, or promotes transfer of an ineffective strategy (Barnett & Ceci, 2002; Condell et al., 2010; Kahney, 1993). Negative transfer is closely linked to *mental set effects*, which occur when an individual perseveres along a particular line of thinking regardless of its potential utility (Öllinger, Jones, & Knoblich, 2008; Pretz et al., 2003; Wang & Chiew, 2010). Specific examples of mental set effects include functional fixedness, which occurs when an individual is unable to re-conceptualise their previous understanding of function or purpose, and *Einstellung*, which involves the mechanical application of a known solution strategy regardless of its relevance or efficacy (Condell et al., 2010; Öllinger et al., 2008).

One important potential outcome of positive transfer is the evolution of a *problem schema* – an organised mental representation (or knowledge cluster) that captures both procedural knowledge and broad solution principles relevant to a particular class of problems (Billing, 2007; Chen & Mo, 2004; Chi & Glaser, 1985; Gick, 1986; Lee, 1992). Both *problem isomorphs* (problems that share identical or near identical underlying relational structures) and *problem homomorphs* (problems that share similar relational structures) can function as a problem class or set underpinning schema induction (Chi & Glaser, 1985; Gentner & Smith, 2012; Kahney, 1993). Problem schemas for particular problem sets are created and stored in long-term memory, and can then be activated, brought into working memory, and applied when cued by relevant features present in a yet-to-be-solved problem (Gick, 1986; Gick & Holyoak, 1983; Thomas, 2008).

Schema formation is closely linked to the development of expertise – in that experts appear to have a “...*store of patterns representing commonly occurring configurations of information in the knowledge domain, and a store of solutions/ operations to apply to them*” (Kahney, 1993, p.90). Ericsson and Kintsch (1995), following an extensive review of skilled performance across a wide range of activities, propose that expertise incorporates the acquisition of refined encoding skills for domain-specific information storage in long-term memory, as well as the development of efficient retrieval structures (organised sets of retrieval cues) permitting rapid and reliable access to relevant information. They also propose that these features provide skilled performers with an expanded working memory capacity for domain-relevant activities (Ericsson & Kintsch, 1995). Experts are thus able to rapidly recognise and classify problem types based on their underlying structural similarity; whereas novices tend to focus on surface features and lack a structured knowledge base from which to work (Chi, Feltovich, & Glaser, 1981; Chi & Glaser, 1985; Condell et al., 2010;

Day & Goldstone, 2012; Gick, 1986; Gorodetsky & Klavir, 2003). Experts are also able to organise information more effectively and infer solutions more quickly based on their understanding of individual problems as instances of a larger hierarchical structure with known solution strategies (working ‘forwards’); whereas novices work within an isolated conceptualisation of the problem and try to use what is already presented as a basis or bridge for supporting various possible solution attempts (‘working backwards’) (Billing, 2007; Day & Goldstone, 2012; Gick, 1986; Kahney, 1993). On this basis, it can be argued that a distinguishing feature of expertise is the ability to apply more effective solution strategies when faced with problems located within the relevant domain (Billing, 2007; Ericsson & Kintsch, 1995; Gick, 1986; Kahney, 1993).

2.2. Problem solving strategies

Problem solving strategies are systematic approaches or processes that guide the selection, implementation, and evaluation of various operators (actions) in order to move effectively from the initial problem state to the desired goal or outcome (Dunbar, 1998; Gick, 1986; Holyoak, 1995; Kahney, 1993; Koichu, Berman, & Moore, 2003; Ohlsson, 2012). These strategies can guide both choice of a particular action before the effect is identified (preference) and decisions as to whether to continue to execute a particular action based on the outcome (evaluation) (Ohlsson, 2012). Both strategy selection and implementation can occur below the level of conscious decision-making or as a result of deliberate, active judgement; and both are influenced by multiple factors related to the nature of the problem task, the individual solver, and the broader problem context (Fum & Del Missier, 2001; Gick, 1986; Ohlsson, 2012). In addition to being highly situation-dependent, strategies can also vary over time and may be combined to solve a single problem (Lee, 1992; Ohlsson, 2012).

Problem solving strategies are either algorithmic or heuristic in nature. *Algorithms* are procedures or strategies that will always ensure a successful solution (assuming correct application) whereas *heuristics*, essentially procedural or strategic shortcuts based on experience, do not guarantee a successful outcome or that the best possible option available will be identified (Condell et al., 2010; Holyoak, 1995; Kahney, 1993). Despite the potential for inaccuracy, heuristic strategies are typically easier to apply, more efficient in terms of time and processing resources (particularly demands on working memory), and better suited to a wider range of problem types (especially ill-defined problems); and are thus more commonly utilised (Billing, 2007; Dunbar, 1998; Holyoak, 1995; Koichu et al., 2003).

Various theoretical approaches have identified a wide range of possible heuristics that can be employed when solving different types of problems (Chen & Siegler, 2013; Gick, 1986; Lee, 1992; Wang & Chiew, 2010). These include *means-end analysis*, which suggests that various operators are chosen in order to successively reduce the distance between the initial problem state and the desired goal state (Kahney, 1993; Newell & Simon, 1972; Ohlsson, 2012; Pretz et al., 2003); *problem decomposition* (also termed *divide-and-conquer* and linked to *hill-climbing*), where a problem is divided into a series of smaller tasks leading towards the ultimate goal and each is then solved sequentially (Gick, 1986; Holyoak, 1995; Lee, 1992; Ohlsson, 2012; Wang & Chiew, 2010); *working backwards*, in other words beginning with the goal and working back through bridging stages to reach the initial problem state in contrast to *working forwards* from the initial state to the goal (Holyoak, 1995; Lee, 1992); and *planning*, which involves both anticipating possible effects before applying a particular action and identifying an effective application sequence (Gick, 1986; Holyoak, 1995; Koichu et al., 2003; Lee, 1992).

Other strategies involve the production of *insight* - an abrupt shift in, or re-organisation of, the original perception or representation of a problem leading to increased understanding and determination of a solution (Condell et al., 2010; Davidson, 2003; Goldstein, 2010; Miller, 2014; Öllinger et al., 2008; Pretz et al., 2003). Methods that may trigger insight include: deliberately focusing on other tasks and setting the problem aside for a period of time (*incubation period or effect*); differentiating between information that is solution-relevant and information that is irrelevant within the problem statement (*selective encoding*); merging and re-combining problem elements (*selective combination*; essentially the same as *synthesis*); comparing elements of the current problem with elements of problems already encountered (*selective comparison*; essentially the same as use of *analogy*); and *shifting modality* (including *visualisation*), where the method of presenting the given information within the problem is redeveloped or altered (Chen & Siegler, 2013; Davidson, 1995; 2003; Davidson & Sternberg, 1984; Holyoak, 1995; Koichu et al., 2003; Pretz et al., 2003; Wang & Chiew, 2010).

Strategies can also be more pragmatically-based, such as: *exhaustive searching*, which involves systematically exploring all possible solution options (assuming the total number of options is manageable); *generation and testing* (also termed *trial-and-error* or *discovery*), which involves identifying and implementing various operators until a successful set is located; *divergent thinking* (linked to *brainstorming*), where as wide a range of solutions as possible is developed and then the best selected; *observation* of others (including *copying*); and *receiving instruction or requesting assistance* (Chen & Siegler,

2013; Condell et al., 2010; Hamlen, 2018; Lee, 1992; Miller, 2014; Pretz et al., 2003; Wang & Chiew, 2010). The notion of using previous experience or problems solved in the past as a base or guide for developing an appropriate solution to the current problem, in other words, *problem solving by analogy*, is also a highly practical strategic approach (Billing, 2007; Gick & Holyoak, 1980; Koichu et al., 2003; Miller, 2014; Polya, 1957, as cited in Gick, 1986; Wang & Chiew, 2010).

In a seminal article focused on students' metacognitive awareness of the problem solving strategies they employed when tackling interpersonal, practical, and study-based problems, Antonietti et al. (2000) were able to synthesise many of the heuristic strategies scattered throughout the literature into five broad strategy clusters: (a) free production; (b) combining; (c) step-by-step analysis; (d) visualisation; and (e) analogy (please refer to Appendix A). The *free production* cluster encompasses strategies such as brainstorming, generation, and divergent thinking; and refers to processes where creative and fluid thinking is encouraged to produce multiple ideas. Associated behaviours include producing multiple ideas regardless of relevance; postponing evaluation; selection from multiple options; and generating ideas as freely as possible. The *combining* cluster involves deliberately or randomly merging existing information or problem elements together in new or unusual ways to generate informative, novel links or patterns leading to the solution; and is epitomised in strategies such as selective combination and synthesis. Associated behaviours include extracting and linking problem elements together in different combinations to those presented; and amalgamating information to form new patterns (Antonietti et al., 2000; Güss & Wiley, 2007; Metallidou & Platsidou, 2008; Miller, 2014).

Combining strategies are closely linked with those within the *visualisation* cluster, which draws together classic methods leading to insight; and refers to those processes that allow a re-representation or restructuring of the problem or a shift in viewpoint to be achieved through a change in perception of the problem's essential features. Typical actions include constructing either physical or mental images; re-imagining the problem scenario; or engaging in visualisation exercises. In contrast, the *step-by-step* cluster encapsulates highly methodical strategies designed to guide the choice of operators when moving from a starting state to a goal state – essentially classic means-end analysis and associated strategies such as planning, decomposition, and working forwards/ backwards. Typical behaviours include creating sub-problems and identifying intermediate goals; creating hierarchies of actions and ordering sequences; and working through the problem in an organised and logical manner (Antonietti et al., 2000; Güss & Wiley, 2007; Metallidou & Platsidou, 2008).

The final cluster, *solution by analogy*, refers to recalling past problems in order to successfully adapt the solution and transfer it to the current problem. This involves identifying the underlying, corresponding principles or relations that are shared between two or more problems and extracting these to form a suitable solution or problem solving schema. Associated behaviours include searching one's memory for previous instances that share elements of the current problem; transferring ideas from previous experience; and recalling successful solutions employed to solve previous problems (Antonietti et al., 2000; Gentner & Smith, 2012; Gick & Holyoak, 1980; Güss & Wiley, 2007; Holyoak, 2012; Metallidou & Platsidou, 2008; Miller, 2014; Yanowitz, 2001).

In addition to creating the five strategy clusters, Antonietti et al. (2000) also evaluated students' perceptions of the extent to which they employed each cluster when solving different types of problems, their relative efficacy, and the ease with which they could be employed. The results, obtained from eighty-three undergraduate students ranging in gender, age, and discipline of study from the University of Milan, indicated that analogy was the most frequently employed strategy overall and for solving both interpersonal and practical problems; while step-by-step methods were the most common for study-type problems. Both analogy and step-by-step methods were also regarded as the most effective and analogy was seen as the easiest to utilise, although step-by step and combining were seen as the hardest to implement effectively. Free production and combining were reported as being the least utilised strategy sets and free production as the least effective set of strategies overall. These same strategy clusters were also utilised by Güss and Wiley (2007), who explored frequency of strategy use cross-culturally in samples taken from Brazil, India, and the USA. Their findings matched those of Antonietti et al. (2000) regarding analogy, which was reported as the most frequently used strategy within all three sample groups.

Although, as indicated from the results reported above, the use of previous knowledge to solve new situations is thus extremely common, it is important to bear in mind that, as with all heuristics, analogy does not guarantee that an appropriate solution will be achieved (Holyoak, 2012; Izsof Jurasova, Biela, & Spajdel, 2014; Ross & Kilbane, 1997). Nevertheless, the findings do serve to confirm the importance of analogy as an easily deployed, relatively effective, and widely utilised heuristic problem solving strategy, particularly in cases where the solver is uncertain of how to progress or feels challenged (Bernardo, 1998; Billing, 2007; Chen & Mo, 2004; Izsof Jurasova et al., 2014; Pedone, Hummel, & Holyoak, 2001; Schelhorn, Griego, & Schmid, 2007; Wareham, Evans, & van Rooij, 2011) - "...*people sometimes solve otherwise intractable problems by forming and*

exploiting analogies with related source cases” (Catrambone, Craig, & Nersessian, 2006, p. 1126). There is also evidence to suggest a link between analogy use and general problem solving efficacy (Blanchette & Dunbar, 2001; Markman, Taylor, & Gentner, 2007). Given this, the need for both a highly developed theoretical understanding of and empirical evidence related to the ways in which previously acquired knowledge can be effectively transferred and deployed during the problem solving process is evident (Barnett & Ceci, 2002; Gentner & Smith, 2012; 2013; Gick & Holyoak, 1980; Nokes, 2009; Reeves & Weisberg, 1994).

2.3. Analogical problem solving

Analogical problem solving is an inferential strategy that consists of adapting a solution procedure from a previously encountered and understood problem to resolve a new problem that shares significant underlying relational similarities or correspondences (Anolli, Antonietti, Crisafulli, & Cantoia, 2001; Corkill & Fager, 1995; Gick & Holyoak, 1980; 1983; Reimann & Schult, 1996). It can be argued that the fundamental skills involved in being able to solve problems analogically are being able to identify elements embedded within problem representations that are structurally similar or analogous, being able to distinguish between relevant similarities and other non-analogous or irrelevant detail within the same representations, and being able to extract and transform the shared information into a workable solution strategy that can be applied to problems of a similar type (Chen & Siegler, 2013; Gick & Holyoak, 1980; Holyoak, 1984; Lee, 1992; Neuman & Schwarz, 1998; Schelhorn et al., 2007). At its heart, analogical problem solving is therefore a quintessential example of positive transfer (Bassok, 2003; Day & Goldstone, 2012; Klein, 1994; Novick & Holyoak, 1991; Reeves & Weisberg, 1994; Speicher & Kehrhahn, 2009), where “...a problem is solved by mapping its components onto a similar problem whose solution path is already known” (Pretz et al., 2003, pp.17-18).

Inherent within the various definitions of analogical transfer is the notion of directionality – problem solving occurs by adapting solutions from past problems to present problems that serve as *analogues* (Barnett & Ceci, 2002; Bearman, Ball, & Ormerod, 2002; Holyoak, 2012). The problem to be solved is referred to as the *target* problem, while the solution strategy to be recalled and adapted is retrieved from the *source* or *base* problem, which is typically more familiar (Blanchette, 2000; Gentner & Smith, 2012; Gick & Holyoak, 1980; 1983). It is assumed that through access to the source problem, resolution of the target problem is made easier; thus transfer from previous problems encountered is seen as both a facilitating mechanism and a key resource (Bernardo, 1998; Corkill & Fager, 1995; Neuman & Schwarz, 1998; Statler, Jacobs, & Roos, 2008).

The link between the source and target problem is fundamentally one of relational similarity (Abdellatif, Cummings, & Maddux, 2008; Condell et al., 2010; Gentner & Smith, 2013; Kaminski et al., 2013) – “...*any two problems can be considered...analogous if they share a common pattern of relationships among their constituent elements, even though the elements themselves [may] differ across the two situations*” (Holyoak, 2012, p.234). *Relational or structural similarity* is determined by the degree to which the key objects within each problem relate to one another in similar ways, in other words, the extent to which underlying relations exist that can be organised into isomorphic relational structures shared between the problems (Bassok, 2003; Chen, Mo, & Honomichl, 2004; Gentner & Smith, 2012; 2013; Nokes, 2009). Structural similarity between two or more problems is an essential prerequisite of analogical transfer, in contrast to surface similarity which plays a mediating but not defining role (Bassok, 2003; Blanchette & Dunbar, 2000; Francis, 1999; Gentner & Colhoun, 2010; Reeves & Weisberg, 1994). *Surface similarity* is determined by the extent to which the two problems share similar objects, properties, attributes, or contextual features, which may or may not share similar underlying relations (Bassok, 2003; Chen et al., 2004; Gentner & Smith, 2012; 2013; Nokes, 2009; Trench & Minervino, 2015; Wong, Ng, Tempel, & Lim, 2017). Clement (1994) notes that surface similarity can obscure structural similarity, and it has been suggested that skill in utilising analogy as a problem solving or learning tool is directly dependent on the ability of the solver to pay attention to and extract the common relational structure regardless of the degree of surface similarity (Bassok, 2003; Zook, 1991).

The level of overlap between analogues in terms of both structural and surface similarity ranges on a continuum, and is closely linked to the concept of *transparency* (Day & Goldstone, 2012; Gentner & Smith, 2012). Analogues are most transparent when surface features that are representative of the shared relational structure correspond (also termed literal similarity) and surface features that are not relevant are distinct; and least transparent when surface features that are structurally unrelated correspond highly on a superficial level (also termed cross-mapping) (Cushen, 2012; Day & Goldstone, 2012; Gentner & Smith, 2012; Reeves & Weisberg, 1994). Transparency is closely connected to and affected by concreteness, which refers to the level of detail conveyed by the analogue, in other words, the extent to which it is conceptually and perceptually rich (Day & Goldstone, 2012; Kaminski et al., 2013; Kubricht, Lu, & Holyoak, 2017). Both transparency and concreteness are thus important potential indicators of difficulty, in that they provide ways in which to judge how accessible the underlying structural similarity between two analogues is likely to be.

In addition to similarity, transparency, and concreteness, there are other intrinsic analogue features that play a role in defining the parameters of analogical problem solving. These include: the extent to which the analogy is complete (isomorphic); the degree of complexity or sophistication inherent in the content to be transferred as well as the amount of information to be transferred; and the origin of the analogy, in other words, whether it was self-generated or presented by an external source (Holyoak, 1984; Mason & Tornatora, 2016; Wareham et al., 2011; Zook, 1991).

Another key factor affecting both surface similarity and transparency is whether the source and target problems are drawn from within the same domain or content area or from different domains; this variation in semantic distance can also be classified as inter- and intra-domain transfer; near and far transfer; or local, regional, and long-distance transfer (Bassok & Holyoak, 1989; Billing, 2007; Chai, Cen, Ruan, Yang, & Li, 2015; Chu & MacGregor, 2011; Clement, 1994; Day & Goldstone, 2012; Forsyth, 2018; George & Wiley, 2018; Ozkan & Dogan, 2012). It is widely agreed that as a result of intrinsic surface discrepancies when analogues are drawn from different domains, distant transfer is usually a more difficult process to carry out successfully, although this is moderated by degree of familiarity with each content area (Corkill & Fager, 1995; Lee, 1992; Lightner, Benander, & Kramer, 2008). Inter-domain transfer, however, is also generally seen as a highly valuable exercise in terms of potential for yielding deeper levels of abstraction and understanding as well as creative or innovative outcomes (Barnett & Ceci, 2002; Chai et al., 2015; Cushen & Wiley, 2018; Gick & Holyoak, 1980; Thomas, 2008; Zook, 1991).

The high degree of potential variability in the nature and form of possible problem analogues serves to highlight their flexibility and wide-ranging applicability; and it is unsurprising that analogical problem solving is an area of interest in a large array of fields ranging from artificial intelligence and computing to strategic practice, theory induction, and general reasoning (cf. Condell et al., 2010; Hammond, Seifert, & Grey, 1991; Haskell, 2009; Statler et al., 2008; Wareham et al., 2011). As a heuristic strategy, solving through adaptation of past experience or knowledge is beneficial in terms of ease of application, reduced cognitive load, and reduced uncertainty; and facilitates connections between a wide set of underlying cognitive skills (Antonietti, 1996; Bassok, 2003; Chan, Paletz, & Schunn, 2012; Gick & Holyoak, 1980). It is also a fundamental mechanism for both theory development and learning, and promotes knowledge production, high-level conceptual processing, and creativity (Chen & Siegler, 2013; Cushen, 2012; Cushen & Wiley, 2018; Francis, 1999; Gick & Holyoak, 1980; Kim & Horii, 2015). Arguably the most important role played by analogical transfer, however, is within educational practice, where it is assumed

that the adaptation of previously acquired solutions to new problems underpins both improved performance and transfer of learning; analogical problem solving thus acts as a critical instructional tool that assists with the structuring, assimilation, and application of knowledge both within and across different content areas (Barnett & Ceci, 2002; Gick, 1986; Forsyth, 2018; Mason & Tornatora, 2016; Mestre, 2002b; Novick & Holyoak, 1991; Richland & McDonough, 2010; Richland & Simms, 2015; Speicher & Kehrhahn, 2009; Thomas, 2008; Wells & Le, 2017; Wong et al., 2017; Zook, 1991). This is particularly significant given the widely accepted overarching goal of education, namely the transfer of essential skills and knowledge beyond the classroom environment (Billing, 2007; Day & Goldstone, 2012; Kaminski et al., 2013; Lightner et al., 2008; Peterson & Wissman, 2018).

2.4. Analogical problem solving: Process

Current models suggest that analogical problem solving consists of a series of component processes centred around “...*the transfer of deep structural characteristics from the base to the target problem*” (Reeves & Weisberg, 1994, p.383) leading to the formation of problem solving schemata (Gick & Holyoak, 1983; Zook, 1991). These include: representation, retrieval, mapping, adaptation, and learning (Anolli et al., 2001; Blanchette, 2000; Holyoak, 2012; Keane, 1996; Klein, 1994; Krawczyk, Holyoak, & Hummel, 2004; Kubricht et al., 2017; Novick & Holyoak, 1991; Thomas, 2008). Although there is agreement that these basic processes underlie all forms of analogical problem solving, there is some variation regarding the number of component processes proposed and the distinctions between them (Gentner & Smith, 2012; 2013).

Representation refers to the creation of a conceptual structure of the problem encountered, in other words, mentally representing and organising features of the problem within a hierarchical structure that defines their relationships and allows them to be manipulated (Billing, 2007; Day & Goldstone, 2012; Lee, 1992; Reeves & Weisberg, 1994; Thomas, 2008). This representation can occur at various and/or multiple levels of abstraction, ranging from highly specific details unique to that particular problem to extremely broad, general propositions (Gick & Holyoak, 1980; 1983; Kahney, 1993; Kintsch & Van Dijk, 1978, as cited in Gick & Holyoak, 1980; Neuman & Schwarz, 1998). For analogical problem solving, a representation of the target problem must be constructed that is sufficiently similar to the representation of the source stored in long-term memory to allow for the overlap to be identified. It is thus critical that the representation be generated at a level of abstraction that contains sufficient detail to be useful but is not over-reliant on superficial aspects (Chai et al., 2015; Cushen, 2012; Gick & Holyoak, 1980; 1983; Holyoak,

1984; Kahney, 1993; Thomas, 2008; Zook, 1991). Gick and Holyoak (1980) propose that the formation of an appropriate problem representation may incorporate parallel processes to those applied during text comprehension. Specifically, they suggest that inference rules such as deletion (removing inessential details), generalization (summarising data), and construction (making inferences) may be implemented to formulate a representation incorporating various levels of generality similar to those found in macrostructure understandings of prose (Gick & Holyoak, 1980; Kahney, 1993; Kintsch & Van Dijk, 1978, as cited in Gick & Holyoak, 1980). In addition, it has been suggested that the representation may also be influenced by or incorporate general semantic knowledge and direct perceptual input (Catrambone et al., 2006; Gick, 1986; Gick & Holyoak, 1980).

It is generally accepted that problem representation will play a strong role in determining whether successful analogical transfer can be executed (Kahney, 1993; Kurtz & Loewenstein, 2007; Schiano, Cooper, Glaser, & Zhang, 1989). One reason for this is the close link between representation and the process of *retrieval*, which involves searching long-term memory to identify and select suitable previously solved problems or problem schema that can act as effective sources for the target (Cushen, 2012; Gentner & Colhoun, 2010; Reeves & Weisberg, 1994; Thomas, 2008). This search is guided by semantically-based retrieval cues located within the representation of the target that allow for conceptual connections to be made to relevant previously stored problem representations (Gentner, 1989; Holyoak, 1984; Kokinov & Petrov, 2000; Novick & Holyoak, 1991; Thomas, 2008). According to Zook (1991), “... *attention to particular features in the mental representation of a problem activates other representations that share those features. Thus, shared features act as retrieval cues*” (p. 54).

Recognition of the similarity between the source and target representations based on structural, solution-relevant features as opposed to superficial features is at the core of successful source retrieval, particularly for cross-domain problems (Bassok, 2003; Catrambone et al., 2006; Gentner, 1989; Gentner & Smith, 2013; Holyoak, 2012; Izsof Jurasova et al., 2014; Thomas, 2008). It is important to note, however, that surface similarities (whether relevant or irrelevant) tend to play a far greater role in guiding or facilitating the retrieval process as they are typically more easily cued and identified, and reduce the cognitive demands inherent in recognition (Bassok, 2003; Blanchette, 2000; Cushen & Wiley, 2018; Kaminski et al., 2013; Kokinov & Petrov, 2000; Markman et al., 2007; Nokes, 2009; Reeves & Weisberg, 1994; Thomas, 2008; Trench & Minervino, 2015). Irrelevant surface similarities typically impede positive transfer (or even facilitate negative transfer) as they tend to be more salient than underlying relational similarities and thus mask

potentially germane source analogues (Bassok, 2003; Day & Goldstone, 2012; Francis, 1999; Kurtz & Loewenstein, 2007; Monaghan, Sio, Lau, Woo, Linkenauger, & Ormerod, 2015; Ozkan & Dogan, 2012; Zook, 1991). In contrast, relevant surface similarities (those that are indicative of or align with a shared relational structure) tend to facilitate positive transfer (Bassok, 2003; Cushen & Wiley, 2018; Holyoak & Koh, 1987; Reeves & Weisberg, 1994; Thomas, 2008; Trench & Minervino, 2015). Evidence suggests that accessing sources through identification of structural similarity also improves as one acquires expertise, through training, or if there is an absence of surface similarity (Chi et al., 1981; Lee, 1992; Reeves & Weisberg, 1994; Thomas, 2008; Zook, 1991).

Retrieval is typically followed by *mapping*, the methodical alignment or matching of aspects in the representations of the source and target problems on a one-to-one basis leading to the creation of a common structure of correspondences supporting further inference (Gentner & Smith, 2012; 2013; Gick & Holyoak, 1983; Holyoak, 2012; Kaminski et al., 2013; Keane, 1996; Krawczyk et al., 2004; Novick & Holyoak, 1991). Through the mapping process, aspects of each representation take on the role of mapped identities (commonalities that correspond to the underlying relational structure); structure-preserving differences (differences that align with the underlying relational structure); structure-violating differences (differences that are not consistent with or alter the underlying relational structure) or indeterminate correspondences (elements that fail to map conclusively) (Holyoak, 1984) – “... *the basic impact of analogical mapping is to focus attention on the commonalities and (usually to a lesser extent) the alignable differences, while backgrounding the nonalignable differences*” (Holyoak, 2012, p.246). Effective mapping for analogy is thus dependent on alignment of the relations between propositions or structural features within the source and the target, as opposed to direct mapping of the target itself or mapping of superficial similarities (Day & Goldstone, 2012; Gick & Holyoak, 1980; Holyoak, 2012; Klein, 1994; Speicher & Kehrhahn, 2009; Thomas, 2008). The identification of systems of relations that incorporate parallel higher order relations shared between the two analogues (structural correspondence) is an essential component of successful analogical transfer (Gentner & Colhoun, 2010; Kao, 2014; Markman et al., 2007; Richland & Simms, 2015; Zook, 1991).

Various analogical theories (cf. for example, structure mapping theory (Gentner, 1983; 1989, as cited in Reeves & Weisberg, 1994); and multiconstraint theory (Holyoak & Thagard, 1985; 1989, as cited in Holyoak, 2012)) propose that there are a number of common guiding semantic, structural, and pragmatic constraints within mapping that people tend to apply, including: *one-to-one mapping* – each element in one representation should match exactly to

only one element in the other representation; *structural consistency* or *parallelism* – elements should correspond across contexts, in other words, one-to-one correspondences should be consistent; *semantic similarity* – items that share semantic meaning tend to map to each other; *systematicity* – preference is given to interconnected, deep relational systems rather than smaller sets of relations; *pragmatic centrality* – preference is given to elements that contribute to achieving the intended outcome or goal; and *adaptability* – preference is given to elements that enable inferences leading to a solution strategy (Blanchette, 2000; Gentner & Colhoun, 2010; Gentner & Smith, 2012; Holyoak, 2012; Kao, 2014; Keane, 1996; Krawczyk et al., 2004; Lee, 1992; Reeves & Weisberg, 1994; Yanowitz, 2001). According to Krawczyk et al. (2004): “...*Empirical evidence indicates that people’s preferred analogical mappings tend to honour each of these constraints ... provided they can be jointly satisfied within the finite processing resources of working memory*” (p. 86).

Mapping is heavily influenced by both preceding experience and working memory capacity (in terms of processing load based on the number and complexity of relations); and has been linked to expertise and level of relational knowledge (Gentner & Smith, 2012; Gick & Holyoak, 1980; Holyoak, 2012; Keane, 1996; Kokinov & Petrov, 2000; Novick & Holyoak, 1991). Alignment is also facilitated if the representations are structurally congruent or similar; and hindered due to increased cognitive load if there are structural differences (Bassok, 2003; Blanchette, 2000; Francis, 1999; Nokes, 2009; Speicher & Kehrhahn, 2009; Zook, 1991). In addition, the mapping process can be affected by surface similarity and transparency, as superficially similar elements are typically easier to align and are often used as a cue for underlying relational similarity (Bernardo, 1998; Cushen & Wiley, 2018; Heydenbluth & Hesse, 1996; Kaminski et al., 2013; Krawczyk et al., 2004; Richland & McDonough, 2010; Ross, 1987; 1989, as cited in Bassok, 2003; Ross & Kilbane, 1997; Thomas, 2008). In situations where superficially similar elements take on different structural roles (cross-mapping), there is a high likelihood of mapping conflict between constraints that may impede transfer (Bassok, 2003; Cushen, 2012; Day & Goldstone, 2012; Gentner & Colhoun, 2010; Holyoak, 2012; Kaminski et al., 2013; Krawczyk et al., 2004).

The mapping process creates a natural division in the structure of the source analogue between those correspondences that constitute the basis for an initial shared structural alignment with the target (causal antecedents) and those that are not initially shared and thus form the basis for further extrapolation (candidate inferences) (Gentner & Smith, 2012; Gick & Holyoak, 1983; Holyoak, 1984). Analogical inference occurs when these unmapped propositions or inferences are imported from the source to the target in order to complete the shared relational structure between the two analogues (Day & Goldstone, 2012; Gentner &

Smith, 2012; 2013; Holyoak, 2012). Each inference is judged based on its factual correctness, structural soundness, goal relevance, generative capacity (for new knowledge), and ease of modification (adaptability); the inference is then either retained and integrated to extend the existing relational structure or discarded as an outcome of the evaluation (Gentner & Colhoun, 2010; Gentner & Smith, 2012; 2013). Inference is thus “...*a natural outcome of the structural alignment process... [and]... a process of relational pattern completion*” (Gentner & Smith, 2012, p.132).

Analogical inference forms the basis for *adaptation*, which refers to the transfer of operational knowledge, in other words, ascertaining, projecting, and modifying a solution strategy inferred from the source to meet the requirements of the target (Anolli et al., 2001; Neuman & Schwarz, 1998; Novick & Holyoak, 1991; Thomas, 2008; Zook, 1991). Adaptability of a known solution strategy depends on the extent to which surface and structural features between the two analogues correspond (parallelism); the utility of these correspondences; the adequacy of the initial mapping; and whether the information to be transferred is more concrete or conceptual in nature, with the latter increasing the complexity of the adaptation process (Holyoak, 2012; Keane, 1996; Novick & Holyoak, 1991). There is also some debate as to whether adaptation involves transfer of the complete prior solution or whether previous experience with the source problem is used as a guide (derivational analogy as opposed to transformational analogy) – evidence appears to suggest that either may occur dependent on contextual factors within the problems themselves (Schelhorn et al., 2007). It is important to bear in mind that adaptation is an inferential process that does not guarantee a successful solution will be identified; and it has been shown to be particularly difficult for problem solvers to enact effectively (Anolli et al., 2001; Holyoak, 1995; Keane, 1996; Novick & Holyoak, 1991).

The final stage of the analogical problem solving process is *learning*, which occurs primarily through schema abstraction (although inference projection, difference detection, and re-representation are other potential analogical outcomes that can also foster knowledge creation) (Gentner & Colhoun, 2010; Gentner & Smith, 2013; Klein, 1994; Mason & Tornatora, 2016; Reeves & Weisberg, 1994). During mapping and adaptation, contextual features and superficial differences between the analogues are to a large degree discarded allowing for a common solution strategy based on the shared relational structure to be disembedded and abstracted (Chen & Mo, 2004; Gick & Holyoak, 1983; Holyoak, 2012; Ozkan & Dogan, 2012; Thomas, 2008). This strategy can then be stored in the form of a memory representation epitomising a general solution method for a particular category of problems, in other words, as a problem solving schema (Chen & Mo, 2004; Corkill & Fager,

1995; Gick & Holyoak, 1983; Holyoak, 1984; Kahney, 1993; Novick & Holyoak, 1991; Speicher & Kehrnhahn, 2009; Thomas, 2008). Reeves and Weisberg (1994) and Anolli et al. (2001) note that schema induction is typically strategic (requiring effort to abstract the shared relational structure) rather than automatic.

Once stored, schemas expedite retrieval, mapping, and application of the solution strategy to subsequent exemplars from the same class of problems as they only maintain information relevant to the shared relational structure and not irrelevant contextual details (Gick & Holyoak, 1983; Holyoak, 1984; 2012; Kahney, 1993; Klein, 1994; Kurtz & Loewenstein, 2007; Richland & Simms, 2015; Thomas, 2008). Schema abstraction is thus both a frequent outcome of the analogical process when two or more analogues are compared and a facilitating mechanism for future analogical transfer (Billing, 2007; Gentner & Colhoun, 2010; Gick & Holyoak, 1983; Holyoak, 1984; Kaminski et al., 2013; Novick & Holyoak, 1991). Although schemas are often regarded as “...*higher-order principle[s] for a category of problems devoid of contextual features...*” (Thomas, 2008, p.257), the extent to which surface details (exemplar-specific information) are maintained when schemata are stored is unclear, particularly if these play a role in facilitating recognition of the underlying relational structure (Gick & Holyoak, 1983; Holyoak, 1984; Reeves & Weisberg, 1994).

Both schema formation and schema activation are seen as key mechanisms for enhancing the comprehension and integration of new knowledge as well as the restructuring and extension of existing knowledge; hence the importance of analogical problem solving in relation to both creativity and education (Billing, 2007; Corkill & Fager, 1995; Kim & Horii, 2015; Lee, 1992; Lipkens & Hayes, 2009; Speicher & Kehrnhahn, 2009; Zook, 1991). It is important, however, to acknowledge that the use of analogy as a method for problem solving or learning can also lead to misconceptions if the schema is misinterpreted or overextended, which may result in negative transfer (Barnett & Ceci, 2002; Bassok, 2003; Yanowitz, 2001; Zook, 1991).

2.5. Analogical problem solving: Prevalence and empirical evidence

“...*Success in using analogies [for problem solving] depends on both recognising the similarity between the two problems, and recalling the solution of the analogous problem*” (Condell et al., 2010, p. 230). Given this, classic experimental studies of analogical problem solving and transfer have tended to follow a similar basic procedure in order to ensure that one or more analogues are available for use by the participant under controlled conditions (Bassok, 2003; Catrambone et al., 2006; Holyoak, 2012). This consists of supplying the

participant with an initial task to complete that incorporates encoding of appropriate source information in the form of a principle or procedure followed at a later stage by a second target task that can be completed or solved through transfer from the provided source (Antonietti, 1996; Barnett & Ceci, 2002; Bassok, 2003; George & Wiley, 2018; Gick & Holyoak, 1980; 1983; Holyoak, 2012; Zook, 1991). The extent to which the target problem was solved analogously can then be judged according to use of the provided principle or procedure as well as additional problem parameters such as overall accuracy and solution time if relevant (Gick & Holyoak, 1980; 1983; Izsof Jurasova et al., 2014; Novick & Holyoak, 1991). This method also allows for a distinction to be drawn between assessing transfer that incorporates recognising or noticing the similarity between the two tasks (widely termed *spontaneous transfer*) and transfer that only involves accurately recalling and applying the solution (termed *directed transfer*) based on whether participants are informed of the link between the two problem tasks or not (Anolli et al., 2001; Corkill & Fager, 1995; Cushen, 2012; Gick & Holyoak, 1983; Kubricht et al., 2017; Richland & McDonough, 2010).

In order for the experimental procedure outlined above to work successfully, it is necessary that the target problem has the potential to be solved in several ways (Novick & Holyoak, 1991). It is also vital that the task information be presented in a balanced way that does not over-emphasise or prevent noticing the potential relevance of the source for the target (Gick & Holyoak, 1983; Holyoak, 1984). In addition, it is important that the information to be transferred from the source is relatively short and simple; and that the target problem is of a sufficient level of difficulty and cannot be solved more easily through other means (Antonietti, 1996; Gick & Holyoak, 1983; Holyoak, 1984). For example, one of the earliest studies of transfer between well-defined, isomorphic problems (moving “missionaries-and-cannibals” or “jealous husbands and wives” from one location to another) was conducted by Reed, Ernst, and Banerji (1974), who concluded that transfer was very restricted and occurred only under certain conditions. In contrast, Luger and Bauer (1978) conducted a similar study using isomorphs of the procedure underpinning the classic “Towers of Hanoi” problem and found that a significant degree of transfer occurred. The inconsistency between these results could possibly be attributed to the particular task used, as the “missionaries-and-cannibals” problem is easier to solve through means-end analysis given the complexity of the procedure to be transferred and the high demands placed on working memory during mapping and adaptation (Holyoak, 1984). Methodological variations may thus play a role in explaining discrepant findings that emerge when interpreting the body of evidence available regarding analogical transfer, particularly results related to transfer occurrence and frequency (Barnett & Ceci, 2002; Reeves & Weisberg, 1994).

One of the most consistent findings within the empirical literature is that provision of an analogical source influences both the way in which subsequent problems are interpreted and the nature of the solution generated (Anolli et al., 2001; Barnett & Ceci, 2002; Catrambone & Holyoak, 1989; Lee, 1995; Reeves & Weisberg, 1994). This principle is epitomised in work conducted by Gick and Holyoak (1980) and Gentner and Gentner (1982). The work carried out by Gick and Holyoak (1980) centres around a widely known insight problem (the *radiation problem*) created and researched by Duncker (1945, as cited in Gick & Holyoak, 1980; Holyoak, 1995). Essentially, the problem proposes that the solver is a doctor treating a patient with an inoperable tumour that could be destroyed if radiation of sufficient intensity is used; however, at the necessary intensity, the rays will also destroy healthy tissue and rays of less intensity will have no effect. The radiation problem is thus ill-defined and relatively abstract in terms of permissible operators; and allows for numerous potential solutions to be generated (Gick & Holyoak, 1980; 1983; Holyoak, 1995; Kahney, 1993). When asked to solve this problem unprompted, Duncker (1945, as cited in Gick & Holyoak, 1980; Holyoak, 1995) found that forty percent of participants gave a *tunnel* type of solution (for example, operating to expose the tumour or inserting a tube and using high intensity rays) despite the constraint regarding not being able to operate; twenty-nine percent gave an *open supply route* type of solution (for example, sending high intensity rays down the throat); and five percent gave an *attack-dispersion* type of solution where multiple low intensity rays were used simultaneously from different directions.

The last solution (attack-dispersion) has become widely known as the *convergence schema*, which proposes that a central object surrounded by objects to be preserved can be converged on with less intense force from multiple directions simultaneously (summation of forces) in order to achieve the objective (Catrambone et al., 2006; Gick & Holyoak, 1980; 1983; Kahney, 1993; Zook, 1991). Multiple analogues from different domains have been developed that can be solved using this underlying schematic principle. These include, for example, the general, the fire chief, the lightbulb, the aquarium, the oil well... (please refer to Appendix A); and various pairings have served as a primary research tool for exploring inter-domain analogical transfer, with one analogue acting as the source and the other (usually the radiation problem itself) as the target (cf. Anolli et al., 2001; Antonietti & Gioletta, 1995; Beveridge & Parkins, 1987; Catrambone & Holyoak, 1989; Corkill & Fager, 1995; Cushen, 2012; Francis, 1999; Gick & Holyoak, 1983; Gick & Paterson, 1992; Holyoak & Koh, 1987; Keane, 1985; Kubricht, Lu, & Holyoak, 2015; 2017; Pedone et al., 2001; Spencer & Weisberg, 1986; Storm & Bui, 2016).

In the seminal study in the field, Gick and Holyoak (1980) conducted two experiments where they manipulated the nature of the solution given to participants within the source analogue. In the first experiment participants were provided with an analogue source about a general attempting to capture a fortress surrounded by mined roads that would detonate if too large a force were sent over them; how the general solved this problem was varied between conditions to reflect either a convergence solution, an open supply route solution, or a tunnel solution. Participants (undergraduate psychology students) were then asked to solve the radiation problem. The results clearly showed that the solution frequency for the radiation problem in each condition was highest for the type of solution reflected in the source given (for example, seventy percent of participants in the convergence condition provided a convergence type solution without being prompted compared to just twenty percent in the tunnel condition, ten percent in the open supply route condition, and none in the control condition). This pattern was replicated across all solution types (Gick & Holyoak, 1980). In the second experiment, the solution provided in the source was the same (the convergence schema), but this was manipulated to read slightly differently in terms of the nature of the problem statement (attacking a fortress versus staging a parade allowing all onlookers to see) and in terms of the constraints between the two conditions. The results indicated that a complete convergence schema was produced by fifty-seven percent of those in the attack-dispersion condition, thirty-one percent in the parade dispersion condition, and only eight percent in the control condition (Gick & Holyoak, 1980).

In a third experiment in the same series, Gick and Holyoak (1980) altered the source passage describing the general's situation to exclude the solution altogether, and then presented both this and the radiation task to participants in the guise of a creative problem solving exercise. Participants were asked to generate as many solutions as possible to both scenarios and were told that the first task (the general) might provide some hints as to how to approach solving the second task (the radiation problem). The intention was to assess if participants would use the solution developed for the general's predicament as a base or source for solving the radiation problem, thus producing evidence of having applied an analogical approach. The results showed that forty-nine percent of the participants produced a convergence-type solution for the general's situation; of these forty-one percent (twenty percent overall) also produced a convergence-type solution for the radiation problem. In addition, fifty-two percent of the participants developed an accumulation-type solution strategy for the general; and forty-two percent of these (twenty-two percent overall) also gave an accumulation-type solution strategy for the radiation problem. Gick and Holyoak (1980) concluded that both types of solutions were produced more frequently across both problems than was likely to occur by chance, suggesting that analogical transfer did take

place (although they also cautioned against drawing strong causal conclusions given the correlational nature of the design).

Taken together, Gick and Holyoak (1980) argued that the results from all three experiments provided evidence that source analogies can be influential in developing target solutions, that the extent to which source analogies are useful depends on both surface and structural similarity, and that provision of a source may induce a form of set effect, in other words, inhibit production of alternate solutions that are not analogous.

In another well-known study supporting these findings, Gentner and Gentner (1982) also conducted two experiments to establish whether there was support for analogies playing a role in influencing how people understand novel content. In their first experiment, Gentner and Gentner (1982) asked their participants (high school and college students) to answer several electricity-related questions, and to then self-identify an analogical model they used that influenced their thinking. The results clearly showed that there were systematic differences in the way in which different types of electrical problems (batteries or resistors) were dealt with based on the analogical model (water-flowing or moving-crowd) that participants self-identified and applied (Gentner & Gentner, 1982). In the second experiment, participants (high school and college students with little previous experience) were taught three distinct potential models (moving-crowd, reservoir, and pump) and were then asked to solve different types of electricity-based problems (parallel resistor and parallel battery). The results provided partial support for various models having a positive influence on performance for different problem types (the moving-crowd model was more effective than the other two for resistor problems). Gentner and Gentner (1982) concluded that on the whole, their findings provided clear support for a *Generative Analogies Hypothesis* which suggests that “...conceptual inferences in the target follow predictably from the use of a given base domain as an analogical model” (p.4).

Although there is strong evidence within the literature that the use of previous knowledge (whether induced in the course of the experiment or taken from general past experience) is commonly applied when attempting to solve a new problem, there is also strong support for the notion that this is a difficult task to enact effectively (Antonietti et al., 2000; Bernardo, 1998; Billing, 2007; Condell et al., 2010; Cushen & Wiley, 2018; Izsof Jurasova et al., 2014; Kahney, 1993; Kubricht et al., 2017; Lee, 1992; Neuman & Schwarz, 1998; Pedone et al., 2001). A second principle that emerges clearly from empirical research in the area of analogical problem solving is that transfer is a highly complex and error-prone process, particularly in relation to analogue retrieval (Gick & Holyoak, 1980; 1983; Kaminski

et al., 2013; Novick & Holyoak, 1991; Thomas, 2008; Wedman, Wedman, & Folger, 1999; Zook, 1991).

Although retrieval failure may occur due to a useful potential analogue not being encoded in the first instance, evidence suggests that it is far more likely that an appropriate source is available in long-term memory but due to difficulties in identifying structural similarity or a lack of appropriate cues, the potential relevance of this source for solving the target is not recognised or noticed (Gentner & Colhoun, 2010; Gick, 1986; Gick & Holyoak, 1980; Kostic, Cleary, Severin, & Miller, 2010; Kurtz & Loewenstein, 2007; Needham & Begg, 1991; Thomas, 2008; Zook, 1991). “...*Many researchers have claimed that failure to retrieve previously learned information that is relevant to a novel problem is the biggest impediment to problem solving*” (Reeves & Weisberg, 1994, p.390). Much of the evidence for this proposition has been drawn from studies exploring spontaneous transfer as compared to directed transfer using both a non-specific and direct hint (Anolli et al., 2001; Corkill & Fager, 1995; Novick & Holyoak, 1991).

One example is another experiment conducted by Gick and Holyoak (1980), who provided participants (university students) with three possible source stories (only one of which, the general, was relevant to the target radiation problem); and then divided them into two conditions – one of which received no hint and one of which received a non-specific hint that the stories might be useful to solve the target. Their results indicated that ninety-two percent of those in the hint condition were able to produce a full convergence solution whilst only twenty percent of those in the no hint condition produced full or partial convergence solutions (Gick & Holyoak, 1980). Across the full series of experiments they conducted, Gick and Holyoak (1980) also found that, on average, approximately ten to fifteen percent of their subjects were able to generate the analogous solution to the target without receiving the source (presumably either through adaptation of a previously stored analogical source or through non-analogical means); and only about twenty to forty percent of their subjects were able to generate an analogous solution without a non-specific hint being given after exposure to a source. In contrast, after a non-specific hint was provided, rates of transfer nearly tripled to between seventy five and a hundred percent (Gick & Holyoak, 1980). They concluded that these results provided strong evidence that spontaneous recognition of the potential relevance of a source was low (typically less than a third of subjects) even in “... *a highly simplified experimental paradigm*” (Gick & Holyoak, 1983, p.5)

Although there are exceptions (cf. Cushen, 2012; Fukumine & Kennison, 2016; Gick & Holyoak, 1983; Keane, 1987; Kubricht et al., 2017), a number of subsequent studies have

identified rates of both spontaneous and directed transfer from a single written analogue source that are either similar or lower to those seen in Gick and Holyoak (1980). Anolli et al. (2001) argue that in many of the studies producing conflicting findings (typically higher rates of spontaneous transfer), the source and target used were very alike, supporting claims that surface similarity enhances spontaneous transfer even in the absence of a hint (Bassok, 2003; Catrambone & Holyoak, 1989; Holyoak, 2012; Keane, 1987). They also, through an extensive review of articles available at the time, present compelling evidence for the notion that “...*there is abundant evidence that people fail to transfer spontaneously the solution procedure described in the source to the target if they are not instructed about the source-target relationship... if we exclude the few cases in which experimental manipulations have produced conditions that are particularly favourable in highlighting source-target correspondences*” (Anolli et al., 2001, pp. 238-239). Numerous theorists have concluded that problem solvers experience great difficulty in recognising the salience of the source without instruction as to its relevance (through either a non-specific or direct hint) across highly variant conditions (Anolli et al., 2001; Bearman et al., 2002; Catrambone & Holyoak, 1989; Cushen & Wiley, 2018; Francis, 1999; Kubricht et al., 2015; Markman et al., 2007; Mason & Tornatora, 2016; Monaghan et al., 2015; Novick & Holyoak, 1991; Reeves & Weisberg, 1994; Richland & McDonough, 2010).

In their own experiments, Anolli et al. (2001) attempted to establish why provision of even a non-specific hint was beneficial for improving transfer by exploring whether retrieval failure was due to non-activation of the source or a lack of awareness of the source-target relationship. Their results consistently supported the latter explanation, suggesting retrieval failure may be an example of inert knowledge, where relevant information has been encoded but is not actively applied (Gentner, Loewenstein, & Thompson, 2003; Needham & Begg, 1991; Trench, Olgún, & Minervino, 2016; Whitehead, 1929, as cited in Gentner & Smith, 2013). Successful retrieval therefore appears to require both being reminded of or accessing the source in long-term memory and recognising its relevance (Anolli et al., 2001; Lee, 1992; Ross, 1989). This proposition aligns with findings of reduced spontaneous transfer rates for analogues that share few surface similarities or are drawn from different domains (Catrambone & Holyoak, 1989; Chai et al., 2015; Gentner et al., 2003; Gentner & Smith, 2012; Holyoak, 2012; Reeves & Weisberg, 1994). Bassok (2003) notes that even minor superficial differences such as changes in phrasing, context, or plot line can impede identification of structural similarity thereby inhibiting retrieval; possibly as a result of context specific encoding or representation (Day & Goldstone, 2012; Gentner & Smith, 2012; 2013; Holyoak, 1995). Provision of a hint is thus advantageous as it reduces the degree of cognitive demand or effort required for analogical solving; recognition falls away as a

requirement of the process and the solver is immediately able to narrow their focus in terms of mapping and adaptation (Bassok, 2003; Catrambone & Holyoak, 1989; Cushen, 2012; Francis, 1999; Holyoak, 2012; Kubricht et al., 2017).

2.6. Conclusion

This chapter has provided a brief but comprehensive overview of the general notion of problem solving as well as various heuristic problem solving strategies commonly utilised when individuals are faced with a novel problem. The prevalence and utility of analogical problem solving as a key heuristic approach has been emphasised; and a detailed description of the process of deploying this strategy has been given. Core trends identified through seminal work in the field have also been summarised, particularly evidence for both the existence of analogical transfer as a key problem solving mechanism and its inherent difficulty. The next chapter builds on this information and provides a broad overview of empirical work conducted with the intention of enhancing both analogical transfer and schema formation.

Chapter 3: Enhancing analogical problem solving

The following chapter summarises a broad range of empirical work undertaken in the field of analogical problem solving with the intention of identifying mechanisms that facilitate enhanced rates of analogical transfer between problem analogues. More specifically, the focus of these studies has been to identify particular factors that can enhance the process of schema formation leading to enriched learning across different contexts. Both experimental work and critiques thereof are summarised; and an overview of more naturalistic work undertaken with the same intention is provided as well.

3.1. Transfer enhancement: Schema formation and quality

Given the importance and prevalence of analogical problem solving as well as its inherent difficulty, it is unsurprising that a large proportion of available theory and research has focused on developing a stronger understanding of the analogical process as a basis for identifying methods for facilitating transfer (Catrambone & Holyoak, 1989; Nokes, 2009; Novick & Holyoak, 1991). The latter exercise is one of particular significance as evidence suggests that skilful identification and productive application of analogy can be enhanced through appropriate training (Catrambone et al., 2006; Cushen, 2012; Kurtz & Loewenstein, 2007; Richland, Chan, Morrison, & Au, 2010).

On the basis of theoretical understanding, it has been posited that schema formation could play a critical role in improving transfer; as schemas contain already acquired and primarily structurally-related information regarding shared commonalities for a class of problems and should thus simplify both retrieval and mapping (Billing, 2007; Catrambone & Holyoak, 1989; Gick & Holyoak, 1983; Zook, 1991). This has been demonstrated experimentally through asking participants to summarise the source information provided; and then correlating the extent to which certain key features of the common solution are represented within the summary with rates of analogical transfer (cf. Corkill & Fager, 1995; Fukumine & Kennison, 2016; Gick & Holyoak, 1983; Novick & Holyoak, 1991; Spencer & Weisberg, 1986). For example, Gick and Holyoak (1983) found that eighty-six percent of those who produced good or intermediate schemas for the convergence principle produced an analogical solution to the radiation problem, whereas only fifty-seven percent of those with poor schemas were able to do the same; and in another experiment found that ninety-one percent of those who produced good schemas were able to generate the convergence solution without a hint while ninety percent of those with poor schemas were unable to

generate the convergence solution even after a hint was provided. Novick and Holyoak (1991) reported significant moderate correlations between schema quality and strength of transfer as well as between schema quality and further generalisation (0.52 and 0.43 respectively). Minervino, Olguín, and Trench (2017) also linked schema quality to rates of retrieval for semantically distant analogues. In another example, Kubricht et al. (2017) found that source comprehension (including understanding of the shared relational structure between the analogues) fully mediated the relationship between fluid intelligence and rates of spontaneous transfer of the convergence solution, thus highlighting the role of schema quality as a determinant of transfer performance.

In contrast, Corkill and Fager (1995) found that quality of the schema induced had no effect on rates of analogical problem solving however they did note that they had relatively few analogical solutions to examine which may have affected their results. They also identified differences in the quality of the summary created based on the extent to which the source was familiar to the participant, suggesting that less familiarity might encourage more careful encoding (Corkill & Fager, 1995). Another exception was Cushen (2012), who found that although certain elements of the summaries created (particularly inclusion of the constraint) were predictive of transfer for the radiation problem using the lightbulb analogue as a source, presence of the core elements of the convergence schema were not predictive of performance.

Despite these, on the whole evidence appears to support the proposition that both schema quality and representational quality are strongly predictive of subsequent transfer performance (Catrambone & Holyoak, 1989; Cushen, 2012; Cushen & Wiley, 2018; Fukumine & Kennison, 2016; Gick & Holyoak, 1983; Lee, 1992; Novick & Holyoak, 1991; Reeves & Weisberg, 1994; Spencer & Weisberg, 1986). It is, however, interesting to note that Kubricht et al. (2017) also found that that participants who completed their measure of source comprehension had a lower rate of spontaneous transfer in comparison to participants who did not (sixty-three percent compared to seventy-nine percent). A possible explanation for this could be that the questions included in the measure strengthened participants' focus on and recall of unique or exemplar-specific source details and thus increased the semantic distance between the source and target (Kubricht et al., 2017). This suggests that although both schema and representational quality are important determinants of successful analogical problem solving, attempts to assess these empirically may interfere with the act of transfer itself as well as measurement thereof (Hostetter, Penix, Norman, Batsell, & Carr, 2018; Kubricht et al., 2017).

3.2. Schema enhancement

Holyoak (1984) notes that “...*Any device that highlights the causally relevant correspondences [between two analogues] will facilitate abstraction of a more optimal schema*” (p.224). This underscores the need to identify specific practices or conditions that may assist solvers to extract core relational similarities and recognise their functional relevance across variant situations (Goldwater & Schalk, 2016; Holyoak, 2012; Hostetter et al., 2018; Markman et al., 2007; Wong et al., 2017). Increased literal similarity (surface and structural similarity) as well as similarity in encoding conditions between the source and target, provision of appropriate cues within the target, and deliberate instruction (hints) as to relevance of the source are among those factors that act as facilitating mechanisms for schema induction (Catrambone & Holyoak, 1989; Holyoak, 1984; Kokinov & Petrov, 2000; Kubricht et al., 2015; Kurtz & Loewenstein, 2007; Richland & McDonough, 2010; Son, Doumas, & Goldstone, 2010). Other factors include the number of analogues available, the nature and extent of training provided, and the modality of source presentation.

3.2.1. Schema enhancement: Number of analogues.

Although schemas can be developed from a lone problem if a high degree of guidance regarding the underlying abstract principle or structure is provided, in general solving a single analogue seldom leads to effective schema induction (Gick & Holyoak, 1983; Holyoak, 1984; Reeves & Weisberg, 1994; Thomas, 2008). In contrast, the provision of two or more analogues appears to promote schema formation as it allows for mapping of a common relational structure to occur (Gick & Holyoak, 1983; Holyoak, 1984; Kahney, 1993; Reeves & Weisberg, 1994). A seminal study in this regard was conducted by Gick and Holyoak (1983), who used four analogues of the radiation problem (the general, the commander, the fire chief, and Red Adair which focused on an oil-well fire) to explore the effect of multiple source provision and source similarity on rates of transfer to the radiation problem. They created three conditions: in the first, participants (university students) received two similar source analogues (either the general and the commander or the fire chief and Red Adair), in the second two dissimilar analogues, and in the third only one relevant analogue as well as a distractor story. Results indicated that there were no significant differences in production of the convergence solution between those who received similar or dissimilar source analogue pairs; however those who received two relevant source analogues as opposed to one relevant source analogue were clearly advantaged for both spontaneous transfer (forty-five percent compared to twenty-one percent) and overall transfer (eighty percent compared to fifty-three percent).

Subsequent research has clearly established that solving multiple examples that share the same isomorphic structure facilitates both schema induction (Condell et al., 2010; Gick, 1986; Klein, 1994; Novick & Holyoak, 1991; Reeves & Weisberg, 1994; Thomas, 2008) and successful transfer (Bearman et al., 2002; Billing, 2007; Catrambone & Holyoak, 1989; Chen & Mo, 2004; Gentner et al., 2003; Kokinov & Petrov, 2000; Kubricht et al., 2015; Kurtz & Loewenstein, 2007). This may be due to greater attention being directed towards relational or structural mapping through encoding of commonalities; as well as to increased opportunities to identify relevant relations and augment the shared representation (Bassok, 2003; Chen & Mo, 2004; Day & Goldstone, 2012; Markman et al., 2007; Zook, 1991). It thus follows that the benefit derived from processing multiple exemplars appears to be incremental in nature (Catrambone & Holyoak, 1989; Holyoak, 2012). It is important to note, however, that this benefit is not automatic or guaranteed as failures in schema abstraction or application may still occur, particularly if the shared structure is obscured by irrelevant surface dissimilarities (Bassok, 2003; Bassok & Holyoak, 1989; Day & Goldstone, 2012; Francis, 1999; Gentner et al., 2003; Mason & Tornatora, 2016; Reimann & Schult, 1996; Richland & McDonough, 2010; Zook, 1991). Gick and Holyoak (1983) note that “...*dissimilar training examples make it more difficult to learn a concept, but allow it to be used more flexibly once acquired*” (p. 21). This aligns with the concept of desirable difficulty, which suggests that surface variability between examples may inhibit immediate encoding but enhance long-term learning (Day & Goldstone, 2012).

3.2.2. Schema enhancement: Instruction.

Providing some form of instructional support or guidance that directs attention towards the underlying structural commonalities and solution strategies that are shared between analogues has been identified as another critical mechanism for improving schema induction (Bassok, 2003; Catrambone et al., 2006; Catrambone & Holyoak, 1989; Ives, 1999; Kaminski et al., 2013; Monaghan et al., 2015; Speicher & Kehrhahn, 2009; Thomas, 2008). Much of the relevant research in this area has focussed on identifying which forms of instruction are effective in promoting knowledge transfer; findings that hold particular significance for the use of analogies as a teaching resource (Billing, 2007; Catrambone & Holyoak, 1989; Gick & Holyoak, 1983; Mason & Tornatora, 2016; Richland & McDonough, 2010; Richland & Simms, 2015).

Supplying multiple analogues in conjunction with explicit directives or scaffolding questions that necessitate their comparison during encoding has been found to be an

effective method of enhancing both schema formation and subsequent transfer (Antonietti, 1996; Catrambone & Holyoak, 1989; Edwards, Williams, Gentner, & Lombrozo, 2014; Gentner & Colhoun, 2010; Novick & Holyoak, 1991; Richland & McDonough, 2010). For example, Catrambone and Holyoak (1989) conducted a study where they explored the simultaneous effects of multiple analogue provision and comparison instructions using a sample of university students. They divided their participants into four conditions based on whether they received two relevant source analogues or one relevant source analogue and a distractor story as well as whether they received instructions to compare the two stories or not (in the form of answering a question as to how the stories were similar). Participants then solved the radiation problem both without and with a hint. Results indicated that the rate of spontaneous transfer was highest for the condition that received two analogues and instructions to compare (forty-seven percent compared to twenty-five percent or less in the other three conditions); and that total transfer was highest for those conditions that received two analogues (seventy-four percent without instruction and sixty-eight percent with instruction).

In another study, Gick and Paterson (1992) demonstrated that supplying an additional source that presented a solution strategy that differed on only one key dimension from the strategy to be transferred (a 'near-miss' example) was useful as a means of highlighting critical solution commonalities. In a similar vein, Gentner et al. (2003) conducted three experiments which explored whether analogical encoding (an adaptation of case-based learning involving diverting attention to shared correspondences between examples thus promoting structural alignment) enhanced schema abstraction among novices learning negotiation strategies. Their results indicated that comparison between cases significantly improved both schema quality and transfer. These findings provide support for the rationale underpinning the use of comparison, namely that it is effective because it intensifies focus and directs attention towards evaluating shared components between analogues thus promoting identification of key structural similarities (Barnett & Ceci, 2002; Billing, 2007; Catrambone & Holyoak, 1989; Day & Goldstone, 2012; Edwards et al., 2014). Comparison may also serve to refine schematic representation and facilitate future analogical access, as shown in a series of studies conducted by Kurtz and Loewenstein (2007) exploring the effects of comparing two unsolved isomorphic target problems on retrieval of a single source that had already been encoded. Minervino et al. (2017) extended these findings by establishing that this effect was only successful if the two target problems compared were analogous; they also found that construction of an analogous target problem (to match the target problem provided) assisted with retrieval of a superficially dissimilar source.

Evidence suggests that the effectiveness of comparison can be enhanced by the intensity of the process undertaken. In another experiment in the series conducted by Catrambone and Holyoak (1989), participants read two source analogues for the radiation problem (the general and the fire chief) and then answered a series of questions requiring them to either simply identify similarities regarding shared goals, constraints, and solution strategies (less directive) or to elaborate on and generalise these (more directive). They were then given ideal answers to these questions and required to reproduce them from memory. Participants in the more directive conditions then answered a third analogue (the aquarium) with a hint to use the previous analogues (rate of directed transfer was sixty-six percent) and then memorized an ideal solution to this third analogue as well. Findings showed that the highly directive comparison instructions produced significantly greater rates of both spontaneous and directed transfer in comparison to less directive instructions (thirty six percent compared to ten percent and seventy percent compared to forty-two percent respectively) as well as substantially improved schemas. These results tally with those of Gentner et al. (2003), who found that the amount of effort expended when comparing was positively related to transfer.

Another potential method of schema enhancement that is closely linked to notions of comparison (particularly elaborative questions) is the process of eliciting self-explanations (Bearman, Ormerod, Ball, & Deptula, 2011; Day & Goldstone, 2011; Edwards et al., 2014; Needham & Begg, 1991; Neuman & Schwarz, 1998). In a series of online experiments, Edwards et al. (2014) contrasted the effects of comparison and self-explanation tasks on solving the radiation problem using nearly two thousand adult participants. Their results indicated that the comparison task was more effective in facilitating spontaneous transfer than exposure to a single source analogue, but was not more effective than exposure to multiple analogues without instructions to compare. Although this contradicts findings from other studies (cf. for example, Catrambone & Holyoak, 1989), Edwards et al. (2014) note that this may have been due to unprompted comparison taking place, possibly as a consequence of demand characteristics. Results regarding the effects of the explanation task were inconsistent – spontaneous transfer increased significantly in one experiment but not another following presentation of two source analogues; and directed transfer improved when one source analogue was presented. Edwards et al. (2014) interpreted their findings as suggesting that explanation could assist learners to detect shared patterns between cases but would be more effective when combined with comparison.

This interpretation is in line with other studies suggesting that self-explanations are typically only beneficial for improving transfer under certain conditions (Bearman et al., 2011;

Edwards et al., 2014; Neuman & Schwarz, 1998; Richland & McDonough, 2010). For example, Neuman and Schwarz (1998) found that self-explanations that could be categorised as clarification, inference, or justification enhanced transfer however reformulation self-explanations had a negative effect. Renkl (1997), using think-aloud protocols, found that learning success could be predicted based on qualitative differences in self-explanation, specifically the extent to which principle-based explanations and anticipative reasoning were employed. Lane and Schooler (2004) were also able to show that when participants were required to describe their reasoning process aloud, in other words, verbalise explanations, they were more likely to focus on superficial commonalities as opposed to structural similarities, suggesting that analogical problem solving is vulnerable to verbal overshadowing effects.

Schema formation may also be influenced by the underlying purpose or explanatory goal attributed to encoding of the source; although the empirical studies available are inconsistent in focus and thus difficult to consolidate effectively (Day & Goldstone, 2012; Zook, 1991). In one such study, Gick and Holyoak (1983) explored whether instructions to summarise the source content would increase transfer by encouraging a higher level of representation than instructions to recall the source verbatim. Their results indicated that there was no significant difference in transfer rate between the two conditions. Antonietti (1996) examined three types of instruction, namely: literal recall, identifying essential features (schematizing), and judging the solution provided (evaluation). His findings indicated significantly higher rates of transfer for schematizing and evaluation in contrast to literal recall; possibly due to these eliciting increased identification of key structural correspondences. This ties in with research conducted by Needham and Begg (1991), which produced results indicating that problem-oriented processing (solving a training problem or explaining its solution before being given an ideal solution) consistently produced a significantly higher rate of transfer than memory-oriented processing (studying the problem and solution for recall purposes) across their series of experiments. In direct contradiction of these findings, however, Craig (1998) identified no significant difference in problem solving performance between memory-oriented and problem-oriented processors (although this may have been due to confounding) and Klein (1994) also found that learning a problem solving strategy through copying or through explaining did not lead to differential rates of transfer.

Several recent studies have focussed on the potential role retrieval practice (i.e. free recall testing) plays in facilitating analogical transfer (Hostetter et al., 2018; Peterson & Wissman, 2018; Wong et al., 2017). Wong et al. (2017) found that retrieval practice enhanced analogical problem solving performance on statistical testing analogues to a

greater extent than repeated studying for delayed testing but not for immediate testing; and argued that this could be attributed to "...*more robust organisation that produces more stable recall over time...*" (p.5). Hostetter et al. (2018) explored the effects of different forms of retrieval practice on both spontaneous and directed analogical transfer using analogues of the convergence schema (inter-domain transfer) in samples of undergraduate students. In their first experiment, they compared the effects of recalling the two source stories in writing from memory (retrieval practice), re-copying the source stories verbatim in writing, or simply re-reading the sources; and in their second experiment they compared the effects of retrieving critical (schema-relevant) or non-critical (irrelevant) information (through guided questions) with simply re-reading either critical or non-critical information. Across both studies, their findings indicated that retrieval practice did not facilitate spontaneous analogical transfer, regardless of whether this was for the source analogues as a whole (general retrieval) or was specific to critical (schema-relevant) information (Hostetter et al., 2018). They did, however, note that rates of directed transfer improved for participants who practiced retrieving critical information (Hostetter et al., 2018). This pattern of results is broadly aligned with the outcomes obtained by Peterson and Wissman (2018), who also found that retrieval practice improved rates of directed transfer in two of their three experiments. In their third experiment, however, retrieval practice did not improve rates of either spontaneous or directed transfer; this was primarily attributed to conditions within the experimental procedure which may have inadvertently advantaged the contrast group (Peterson & Wissman, 2018).

Another possible mechanism for enhancing schema abstraction and analogical transfer is simultaneous presentation of a source analogue and a summary of the isomorphic relational structure or abstract principle (Bearman et al., 2002; Blanchette, 2000; Gick & Holyoak, 1983; Kahney, 1993; Klein, 1994; Markman et al., 2007). Gick and Holyoak (1983) found no support for this in one of their experiments where they explored the effects of providing either a single source analogue (the general), a verbal summary of the convergence principle, or both to participants; transfer rates for spontaneous and directed transfer for the radiation problem did not differ between the conditions. Provision of the same verbal summary was effective, however, when combined with encoding of two source analogues (the general and the fire chief) in another experiment in the same series; rate of spontaneous transfer (sixty-two percent), rate of overall transfer (eighty-two percent), and schema quality (forty-four percent with good quality descriptions) were all significantly higher for the condition that received the verbal description of the underlying principle than for the condition that did not (forty percent, sixty-seven percent, and ten percent respectively).

Clement (1994) also found that transfer improved if participants were provided with base analogues in which the relational structure was presented explicitly (schematic description) or with reduced domain-specific and contextual detail (manifest description); and suggested that: “...*manifest analogs may embody a useful level of representation because they contain enough specificity to aid comprehension, but at the same time they allow relatively easy generalization of their structure to new contexts*” (p.30). This aligns with suppositions that schemas may contain both abstract relational knowledge and a degree of contextual surface information (Gick & Holyoak, 1983; Novick & Holyoak, 1991; Reeves & Weisberg, 1994; Thomas, 2008). Yamasaki (2001) found that presenting the convergence principle as a lesson facilitated spontaneous transfer and Hsu and Wedman (1994) identified a principle-based content emphasis as advantageous in comparison to a procedure-based emphasis. On the whole, evidence seems to suggest that exposing participants to both an overt summary of the isomorphic solution strategy and multiple analogues is more effective for enhancing schema formation and transfer than using either option individually (Reeves & Weisberg, 1994).

Examples tend to be more easily engaged with and understood as they provide more tangible instantiations of abstract embedded principles (Gentner et al., 2003; Gick & Holyoak, 1983; Ross, 1987). Schema development can also be improved through creating conditions that allow for exposure to multiple concrete examples drawn from different contexts - “...*the provision of diverse, representative source instances along different dimensions allows for the construction of a less context-embedded and/or procedure-bound, and thus more flexible and powerful, schema*” (Chen & Mo, 2004, p. 596). This is particularly effective if combined with cueing (giving either general or directive hints or prompts), which facilitates separation and extraction of the shared relational structure (Lee, 1995; Ozkan & Dogan, 2012; Richland & McDonough, 2010; Speicher & Kehrhahn, 2009). Novick and Holyoak (1991) also found that transfer success for mathematical analogues could be increased further if the hints provided were not merely abstract or conceptual in nature; but included concrete information that reduced the effort required for adaptation.

In contrast to this, Kaminski, Sloutsky, and Heckler (2008, as cited in Kaminski et al., 2013) suggest that generic instantiations may be more beneficial than concrete or perceptually rich examples as they contain less extraneous detail and are less familiar (thus aiding encoding and identification of structural correspondences) (cf. Clement, 1994). Kaminski et al. (2013) provided additional evidentiary support for this proposition in a series of five experiments which consistently indicated that increased concreteness blocked transfer of mathematical concepts. Kubricht et al. (2017) also proposed that the higher than

average rates of spontaneous transfer seen in their study could have been as a result of their use of a source story that was “...*less rich in details irrelevant to the convergence solution...*” (p.585). Day and Goldstone (2012) argue that this supports the necessity of creating a balance between abstraction and concretization when using source examples, further noting that:

“...presenting information via concrete examples may lead to mental representations that are overly “bound” to a particular context and may interfere with a person’s ability both to recognize new situations where their knowledge could be relevant and to apply their knowledge in an appropriate way. On the other hand, efforts to circumvent these problems by presenting information abstractly, with minimal specific context, may seriously impair the learner’s ability to accurately represent the information at all. Educators may, reasonably, feel faced with the unappealing task of choosing between comprehensibility and applicability” (p.158).

This is in line with the proposed use of manifest analogues (Clement, 1994).

Another way in which examples can be used to promote schema formation is encouraging self-generation of additional analogues (Blanchette & Dunbar, 2000; Holyoak, 2012). For example, Nikata and Shimada (2005) conducted two experiments where university students were exposed to base problems (either a convergence schema isomorph or a word ratio isomorph) and were then split into a control condition and a problem-posing condition that had to create and solve their own analogue to the base problem. In both experiments the problem-posing condition outperformed the control condition that received only the pre-developed analogue. Structurally similar examples also typically form the basis of teaching interventions that focus on knowledge development through analogical transfer (Billing, 2007; Ives, 1999; Jausovec, 1993; Muldner & Conati, 2010; Novick & Holyoak, 1991; Richland & McDonough, 2010). Brown and Clement (1989) identified several tutoring practices they felt would enhance analogical instruction and avoid misconceptions, including: using an anchoring example; using intermediate or bridging analogies to develop the link between the anchoring example and the target; creating an interactive teaching environment; and building enriched explanatory models.

“...It seems most likely that all of these factors - more examples, more-directive comparison instructions...- can contribute to the acquisition of generalized schematic knowledge of a problem category, which in turn allows more flexible transfer” (Catrambone & Holyoak, 1989, p.1154). It is important to bear in mind, though, that although various instructional methods have been shown to be effective in promoting schema formation, the

process remains open to potential mapping or adaptation failures as well as negative transfer effects (Billing, 2007; Condell et al., 2010; Kahney, 1993).

3.2.3. Schema enhancement: Modality.

Although presentation modality (form of expression) has only recently become a topic of interest in relation to transfer, there is increasing evidence for the effect it may have on schema induction (Barnett & Ceci, 2002; Day & Goldstone, 2011; 2012; Kaminski et al., 2013; Kubricht et al., 2015; 2017; Markman et al., 2007). This evidence aligns with theoretical propositions that both perceptual and conceptual information are integrated during the problem representation process; and that perceptual input may form the basis from which structural abstractions can be generated (Day & Goldstone, 2012). Modality may thus be an important determinant of retrieval and schematic access as well as adaptation (Holyoak, 2012; Kokinov & Petrov, 2000).

Given the dynamic nature of the convergence schema, it is unsurprising that much of the available research related to modality has focused on exploring the effects of visual presentation of the source on transfer to the radiation problem (Beveridge & Parkins, 1987; Holyoak, 2012; Kubricht et al., 2015; 2017; Pedone et al., 2001). Gick and Holyoak (1983) conducted two experiments where they presented participants with a visual summary of the convergence principle in the form of a static two-part diagram (the first part consisted of a single large arrow and the second of a circle of smaller arrows all pointing centrally inward). Their results indicated that provision of the static diagram did not enhance either spontaneous or directed transfer if this was presented alone or simultaneously with one story analogue. In contrast, exposure to two story analogues as well as the diagram led to significantly increased rates of both spontaneous and overall transfer as well as increased quality schema production. Despite this, Gick and Holyoak (1983) concluded that inclusion of the diagram was an ineffective mechanism for enhancing schema induction. Pedone et al. (2001) further established that static diagrams were not effective as sources unless a hint regarding their utility was given, even if the static diagrams were extended to represent additional intermediate solution states. They also found that augmenting the static diagram with a verbal summary of the convergence principle led to an increase in spontaneous transfer rate, possibly as a result of providing an appropriate semantic context for interpretation. Both Beveridge and Parkins (1987) and Pedone et al. (2001) noted that the inadequacy of static diagrams as a source may have been due to a failure to adequately represent all of the critical features of the convergence principle.

To address this, Beveridge and Parkins (1987) conducted a series of transfer studies using both child and university student samples in which they explored the effects of verbal source analogues and diagrammatic source representations of the convergence schema. They improved the original diagram created by Gick and Holyoak (1983) by using both a more detailed two-part diagram and a coloured strip display that captured not only the spatial arrangement of the forces but also the summative effect through an increase in intensity. Their results indicated significantly higher rates of transfer when either new diagrammatic representation was used as a source in comparison to presentation of the older version of the diagram or the analogue alone, particularly for spontaneous transfer in adults (eighty-two percent if the improved diagram was given and ninety-five percent if the coloured strip display was given). Although not based on the convergence schema, other studies have also provided evidence for the efficacy of more elaborated visual cues. For example, Chen (1995) found that if superficial and procedural similarity of schematic source pictures was increased, transfer performance improved as well. Chen, Mo, Honomichl, and Sohn (2010) were able to demonstrate that provision of a detailed visually-based cue could activate relevant sources stored in long-term memory over a considerable time period (specifically a folk-tale learnt in childhood in an adult sample); providing additional support for the notion of representations incorporating at least some degree of perceptual information.

Pedone et al. (2001) explored whether animations (visual representations that incorporate kinaesthetic elements representing implied directed motion) might serve to further enhance transfer of the convergence principle. Across three experiments, their results consistently indicated that those participants who were exposed to animated source versions representing convergence produced significantly higher rates of spontaneous and total transfer. Further support for the efficacy of supplemental animations as opposed to static diagrams was provided by Kubricht et al. (2015; 2017), who compared the effects of providing only a verbal analogue, a verbal analogue and a static diagram, and a verbal analogue and an animation as sources for the radiation problem. Provision of the story analogue and animation substantially improved spontaneous transfer (eighty-one percent as compared to fifty-five percent for the verbal-only condition and fifty percent for the verbal-diagram condition) and total transfer (ninety percent as compared to eighty-three percent for the verbal-only condition and sixty-nine percent for the verbal-diagram condition). They also found that animations improved comprehension of the verbal source and were most beneficial for participants with lower scores on a measure of fluid intelligence (Kubricht et al., 2015; 2017). In a follow-up study, Kubricht et al. (2017) also found that the provision of supplemental animation moderated the relationship between fluid intelligence, source comprehension as a mediator, and spontaneous transfer, such that animation was most

beneficial for participants with lower fluid intelligence scores. They proposed that animation may be particularly useful as a means to highlight key structural relations and reduce working memory demands, thus enhancing selective encoding. They also proposed that animation could “...ground a verbal problem in a dynamic perceptual experience, creating the benefits associated with multimedia instruction...” (Kubricht et al., 2017, p.585). Additional evidence also suggests that both retrieval and schema quality can be enhanced if the source is presented as a video that integrates visual and dynamic elements (cf. Chen & Siegler, 2013; Goh, Tan, & Choy, 2012).

There is very little research that has explored the direct effect of a purely kinaesthetic source on transfer, although extrapolation from studies in embodied cognition suggests that incorporating physical action may be beneficial for enriching representation and reducing cognitive load (Catrambone et al., 2006; Day & Goldstone, 2012; Goh et al., 2012; Kubricht et al., 2015; 2017). Catrambone et al. (2006) explored whether transfer performance for the radiation problem could be enhanced through asking participants to verbally recall the source story and simultaneously represent it through enactment with wooden blocks as compared to verbal recall alone or verbal recall and sketching of a representative diagram. They identified no significant difference in total transfer performance between the conditions once a hint had been provided; however spontaneous transfer in the enactment condition was significantly higher than in the other two conditions, supporting the potential benefit of enactment for schema activation. There is also minimal research that has examined the influence of verbal presentation of the source; although Markman et al. (2007) did explore the effect of spoken presentation on relational retrieval. Their findings suggested that modality did not influence the relative efficacy of object similarity as a retrieval cue however verbal presentation did lead to more relational reminding than written presentation. Holyoak (2012) notes that this result could also potentially be attributed to a reduction in cognitive load.

3.3. Transfer and schema enhancement: Ecological validity

When viewed as a whole, the balance of available evidence suggests that introducing mechanisms that serve to highlight the underlying relational structure shared by analogues can improve both rate of schema induction and schema quality as well as analogical transfer (Gentner & Smith, 2012; 2013; Holyoak, 2012). It is critical to note, however, that this data is drawn almost entirely from laboratory-based, experimental studies; this has led to questions being raised regarding the applicability of the findings across different environmental and temporal contexts (Barnett & Ceci, 2002; Chen et al., 2004;

Gentner & Smith, 2012; Klein, 1994; Rosenthal & Rosnow, 2008; Stangor, 2015).

Furthermore, the traditional method of studying analogical problem solving (provision of a source followed by assessment of spontaneous and/or directed transfer to a target) has similarly been critiqued as regards generalisability (Barnett & Ceci, 2002; Day & Goldstone, 2012; Dunbar, 2001, as cited in Trench & Minervino, 2015; Gentner & Smith, 2012; Trench & Minervino, 2015). Barnett and Ceci (2002) note that “...*generalizing from abstracted, lab-based experimental work is problematic, unless the context to be generalized to is that of abstracted, lab-based tasks...*” (p. 632).

Although “...*imperfect knowledge is characteristic of many instructional situations*” (Novick & Holyoak, 1991, p.399), one of the key limitations of the traditional method that has been identified is limited exposure to and opportunity for processing of the relevant source information. This is not only potentially problematic on pure methodological grounds such as inaccurate measurement and possible underestimation but also highlights the restrictive nature of the assessment of transfer occurrence as a whole (Lobato, 2006; Nokes, 2009; Novick & Holyoak, 1991). Specifically, transfer is typically only deemed to have occurred if the participant utilises a relatively constrained principle or procedure presented in the source to address the target; the scope of the phenomenon is thus limited on the basis of what is judged appropriate by the researcher as an expert (Day & Goldstone, 2012; Lave, 1988; Nokes, 2009). “... *Classical transfer studies privilege the perspective of the observer and rely on models of expert performance, accepting as evidence for transfer only specific correspondences defined a priori as the ‘right’ mappings*” (Lobato, 2006, p.434). This approach is inconsistent with understandings of analogical and schema-based learning as life-long, continuous, and experientially-based; and discounts the role of previously acquired knowledge and understanding in shaping current conceptualisation (Antonietti, 1996; Day & Goldstone, 2012; Holyoak, 2012; Lave, 1988; Lee, 1992; Novick & Holyoak, 1991).

Another related aspect of the process that has received criticism is the tendency to present source material and the target task in the same context and within a close timeframe to one another. Although often a practical necessity, this may undermine the extent to which the resultant outcomes represent genuine occurrences of far transfer or creative thinking across different settings (Catrambone & Holyoak, 1989; Chen et al., 2004; Cushen, 2012; Reeves & Weisberg, 1994). The assessment of directed transfer (particularly provision of a hint) has been critiqued for essentially the same reason, namely concern as to the extent to which this is authentic given the phenomenon under investigation (Barnett & Ceci, 2002; Klein, 1994). Anolli et al. (2001) note that in real-world analogical problem solving, the target and source are not usually presented in close proximity and, excluding cases of deliberate

instruction, are seldom linked through an external device such as a hint. Additional concerns raised include difficulties in balancing the degree of deception or disguise surrounding presentation of the source (to avoid over- or under-emphasis of the potential connection to the target); and the extent to which it is possible to isolate specific elements of the process given its interactive nature (Anolli et al., 2001; Kahney, 1993; Lee, 1992).

In recognition of these limitations, and despite the methodological difficulties posed, a number of researchers have attempted to explore analogical problem solving in ways that more closely approximate real-world cases of transfer and that are more ecologically valid; an extension that is important for both enhanced theoretical understanding and pedagogic practice (Blanchette, 2000; Catrambone & Holyoak, 1989; Chen et al., 2004). This includes attempts to explore contextual effects directly as part of the experimental process as well as studies conducted under more naturalistic conditions.

3.4. Analogical problem solving across contexts: Experimental work

Experimental evidence suggests that both retrieval and spontaneous transfer are impeded when contextual factors are altered or their similarity reduced during the analogical solving process (Catrambone & Holyoak, 1989; Francis, 1999; Holyoak, 2012; Reeves & Weisberg, 1994; Spencer & Weisberg, 1986). In a seminal study exploring this issue, Spencer and Weisberg (1986) provided all participants with two source analogues to the radiation problem (the general and Red Adair). They then created four conditions based on whether participants were given the target task (the radiation problem) in the same setting (as part of a psychology experiment conducted by the same researcher) or a different setting (as part of an in-class demonstration conducted by a different instructor) as well as whether participants were asked to solve the target immediately or after a slight delay (approximately six minutes). No participants in the delayed-different context condition produced the convergence solution despite having been given two source analogues and regardless of the quality of the schema description they produced. Spencer and Weisberg (1986) thus concluded that spontaneous transfer was severely inhibited by even relatively minor contextual and temporal shifts. They were not, however, able to conclusively establish which of the contextual changes (setting or time) was more obstructive.

Catrambone and Holyoak (1989) attempted to refine this conclusion by exposing all participants to two source analogues and a change of context (completing a questionnaire for a social psychology experiment between the source and target tasks) but varying whether participants were given explicit instructions to compare the two analogues as well

as the time delay between completion of the source and target tasks (thirty minutes or one week). Their results showed that rate of spontaneous transfer was exceptionally low following even a short delay (approximately ten percent after thirty minutes and approximately six percent after one week) regardless of whether participants were instructed to compare or not. This consistently low rate of spontaneous transfer across all conditions was interpreted as indicating that contextual change was more likely to obstruct successful transfer than temporal span. They also found that rates of directed transfer were relatively high even after the longer time delay, suggesting that the difficulty lay in recognising the relevance of the encoded sources rather than a lack of encoding (Catrambone & Holyoak, 1989). In a later study, Lee (1995) also established that time interval did not significantly affect transfer when considered in isolation; however Reeves and Weisberg (1994) note that any substantive time delay is often accompanied by other contextual changes thus the potential for interactive effects is high.

Although the reduction in rate of spontaneous transfer elicited by context-based changes appears to be both consistent and strong, there is evidence that this can be mitigated if steps are taken to facilitate retrieval. This includes provision of a hint as well as enhancement of literal or surface similarity (Catrambone & Holyoak, 1989; Reeves & Weisberg, 1994; Zook, 1991). For example, Keane (1987) was able to show that when a source analogue from the radiation problem was also drawn from the medical domain and thus shared numerous semantic similarities, a high rate of retrieval (eighty-eight percent) was obtained despite a time delay and context change. Catrambone and Holyoak (1989) were also able to illustrate that altering the wording of the source analogue in order to better highlight solution-relevant features produced improved rates of spontaneous transfer even after a time delay. In another experiment, they were able to demonstrate that provision of three source analogues in conjunction with detailed comparison instructions produced relatively high rates of spontaneous transfer (seventy-four percent) and overall transfer (ninety-two percent) even after a one week delay between the source and target tasks. Catrambone and Holyoak (1989) suggested that this was a consequence of creating extended opportunities for development of a schematic understanding of the particular class of problems represented; thus allowing for robust transfer effects. “...*If the comparison instructions are extensive and the target problem is phrased in a way that cues an important feature from the source analogs [sic], then transfer is greatly improved*” (Catrambone & Holyoak, 1989, p.1154). Unfortunately, although effective, almost all of these measures remain open to the criticism that they are artificial and non-representative of real-world transfer phenomena (Chen et al., 2004).

3.5. Analogical problem solving in more naturalistic settings

Both anecdotal evidence and observational studies have clearly shown that analogy is widely used as a vehicle for transmitting knowledge, enriching communication, and solving problems across a wide array of fields (Blanchette & Dunbar, 2002; Holyoak, 1984; Kao, 2014; Krawczyk et al., 2004; Yanowitz, 2001). Analogical reasoning and conceptual metaphors underpin everyday work and conversation in areas as diverse as science, medicine, law, philosophy, literature, advertising, architecture, and comedy; and assist with a range of tasks including theory formulation, data interpretation, and explanation and exchange of ideas (Chai et al., 2015; Day & Goldstone, 2012; Dunbar, 1997; Gentner & Smith, 2012; 2013; Kageyama, Shimazu, Taguchi, Nagata, & Magilvy, 2017). This, in conjunction with the critiques raised regarding more traditional and experimental methods, has led to an increased interest in exploring analogical problem solving as it occurs in real-world environments or more generalizable circumstances (Blanchette, 2000; Trench & Minervino, 2015; Wong, 1993).

Studies carried out in more naturalistic contexts or conditions have produced a number of interesting findings, certain of which support conclusions drawn from work in the more traditional paradigm and others of which challenge these. For example, Bearman et al. (2002) explored the way in which analogies were used by final-year management students while completing a decision-making task working in groups through audio-recording their discussion. The students were not provided with any pre-defined instructions regarding what knowledge could be applied to solve the task and were not given any source material. After the task was completed, Bearman et al. (2002) identified eighty-six analogical instances used by the students, seventy-seven percent of which were based on structural mappings. This suggested that even relative novices were able to spontaneously identify and utilise structural relations when given the opportunity to draw on all of their previously stored knowledge; a result that contradicts established notions of novices tending to focus on surface relations (Chi & Glaser, 1985; Day & Goldstone, 2012; Gick, 1986; Gorodetsky & Klavir, 2003). Bearman et al. (2002) did note, however, that it was not possible to distinguish the extent to which the group-work element may have influenced this and cautioned against making direct comparisons with previous findings given the substantive methodological differences.

Despite this concern, a higher utilisation of cross-domain or distant analogies based on shared, deep structural features than might be suggested by laboratory-based findings has been identified in several naturalistic studies; a phenomenon termed 'the analogical paradox'

(Bearman et al., 2002; Blanchette & Dunbar, 2000; Dunbar, 2001, as cited in Trench & Minervino, 2015; Gentner & Smith, 2013; Trench & Minervino, 2015). For example, Blanchette and Dunbar (2001) analysed published newspaper articles covering a referendum campaign and found that over two thirds of the analogies used were distant in nature and superficially dissimilar; and Kretz and Krawczyk (2014) found that use of analogies based on superficial similarities were relatively infrequent during discussions by economic experts. Blanchette and Dunbar (2000) suggested that the discrepancy in rate of primarily structural analogy use between the different setting types could be due to restrictions imposed by the forced retrieval of a pre-defined source typical in most experiments (termed the reception paradigm). To prove this, they altered the task requirements to reflect a production paradigm where participants were asked to freely generate sources for a given target. Their results, in line with those of Bearman et al. (2002), suggested that once the nature of the given task was adapted, a majority of the analogical sources generated both individually and in a group setting were drawn from distant domains and represented complex structural understandings.

Although possibly reduced, the role of superficial similarities in guiding everyday use of analogy is still important to consider; and many of the analogical instances imparted during everyday communication and problem solving have been shown to be literally similar (sharing both surface and structural features) (Gentner & Smith, 2012; Kretz & Krawczyk, 2014). The 'analogical paradox' itself has also been directly challenged in recent work by Trench and Minervino (2015), who conducted two experiments. These were designed to retain the advantages of the production paradigm utilised by Blanchette and Dunbar (2000) - primarily higher ecological validity based on generating analogies using the participants' own sources drawn from extra-experimental memory in response to a highly realistic target situation. They were also, however, designed to address certain methodological concerns raised regarding the original study, specifically the possibility of analogy fabrication and a potential imbalance in availability of 'near' versus 'distant' sources (Trench & Minervino, 2015). Their findings directly contradicted those of previous naturalistic studies, as both experiments strongly supported the role played by superficial similarity in retrieval. Trench and Minervino (2015) noted that

"...Having remedied the insufficiencies detected in the production paradigm as originally implemented, the results of both experiments converge in demonstrating that superficial similarities play a crucial role in the retrieval of naturally encoded sources during analogy generation... our results run counter to the claim that the dominance of superficial similarities in retrieval is rooted in the artificiality of the tasks and materials used in traditional experiments" (p.1312).

Thus, both the extent to which findings across experimental and naturalistic studies support or contradict each other and possible explanations for these alignments and discrepancies remain as open questions, and merit further exploration.

One possibility that has been proposed is that the extent to which superficial similarity is focused on may depend on the purpose of the analogy (Bearman et al., 2002; Dunbar & Blanchette, 2001; Chai et al., 2015; Trench & Minervino, 2015). For example, it has been suggested that superficial or literal analogies are most often used for illustrative or explanatory purposes while structurally-based analogies are most often applied during problem solving (Bearman et al., 2002). Blanchette and Dunbar (2001) found that source selection for analogies in the political domain (analysis of a referendum campaign) depended heavily on the aim or intention informing use of the analogy as well as the perceived extent to which the source would be able to evoke an emotional reaction. In another study, Chan et al. (2012) recorded problem-solving discussions among scientists working on the Mars Rover Mission and found that analogies were often used as a means of reducing uncertainty. This suggests an alignment between naturalistic research highlighting goals or pragmatic purpose as an important determinant of analogical retrieval and mapping and formal theory proposed by Holyoak (1985; 2012) and Holyoak and Thagard (1989; 1997, as cited in Ozkan & Dogan, 2012; Reeves & Weisberg, 1994).

Additional studies focusing on the everyday use of analogy during explanation and problem solving have extended the findings of Blanchette and Dunbar (2000) and Bearman et al. (2002) regarding the implications of allowing a more open or unrestricted choice of source. For example, Chen et al. (2004) found that long-term spontaneous source retrieval and application based on knowledge acquired during childhood (children's folk tales) was possible when participants were not given a pre-defined source during the experiment and were instead free to draw on whatever information they had available in long-term memory that they identified as relevant (avoiding issues of 'directed reminding'). This was echoed in work by Wedman, Wedman, and Folger (1996), who found that participants who successfully solved analogous problems drew on wider life experiences and not just the given source in a think-aloud protocol study using forty undergraduates. Schliemann and Nunes (1990) were also able to highlight the value of drawing on lifelong experience as a means of developing heuristic strategies when they studied problem solving among fisherman. Wong (1993) conducted a study in which teachers were asked to self-generate analogies as a means of enriching their explanations of various scientific phenomena without any source constraints being imposed. The results indicated that the self-developed analogies supported enhanced knowledge transmission, stimulated novel insights, and

augmented understanding. These findings lend support to critiques regarding the potentially negative impact of focusing only on a pre-defined source during traditional experimental studies (Day & Goldstone, 2012; Lobato, 2006; Nokes, 2009).

The apparent benefit of being able to draw on accumulated knowledge during analogical problem solving lends support to propositions that effective transfer may depend on an interaction between new information and existing knowledge stored in long-term memory (Day & Goldstone, 2012; Holyoak, 2012; Lee, 1992). Specifically, long-standing schematic representations appear to be both altered by and to shape new perceptual and conceptual input as it is made available; which in turn influences the way in which a given target problem is interpreted and solved (Day & Goldstone, 2012; Holyoak, 2012; Kokinov & Petrov, 2000; Vendetti, Wu, Rowshanshad, Knowlton, & Holyoak, 2014a). This aligns with research by Monaghan et al. (2015), who conducted two analogical problem solving experiments in which they varied whether participants were kept awake or slept during a twelve hour interval between exposure to the source and target. Their results indicated that those participants who had slept outperformed those who had not; and that there was a positive correlation between performance and sleep duration. Monaghan et al. (2015) hypothesised that the benefit of sleep may have been due to its proven ability to facilitate the assimilation of new knowledge into memory – including “...*sleep-dependent transfer of information from hippocampus to neocortex...where new information is integrated with previous experience*” (p. 29). In another study, Blanchette and Dunbar (2002) demonstrated that information drawn from a source regarding prohibition of alcohol and applied to a debate regarding legalisation of marijuana could not be distinguished by participants in terms of where it originated. Blanchette and Dunbar (2002) suggested that this provided evidence for “...*the analogical insertion effect, in which analogical inferences are integrated unknowingly into mental representations of the target domain*” (Gentner & Smith, 2012, p.136); these cannot later be separated from the original information presented. Holyoak (2012) notes that these analogical inferences may then become regarded as factual; and also that this integration may be both subconscious and unintentional.

3.6. Transfer as a deliberate activity

Along with other findings, the *analogical insertion effect* raises some interesting and currently open questions regarding the level of awareness that informs the transfer process. Although analogical reasoning is typically regarded as a deliberate, active, and conscious exercise; there is a school of thought that proposes that *implicit transfer* may also occur, where the source is not consciously or directly recognised as framing interpretation or

solution of the target (Chen et al., 2004; Day & Goldstone, 2012; Gentner & Smith, 2012; 2013; Holyoak, 2012; Trench et al., 2016). For example, Kostic et al. (2010) conducted three experiments using four-term analogies which indicated that people could detect analogical resemblance between a source and target without being able to explicitly recall the source. Similarly, Day and Gentner (2007) found that “...participants were found to use information from a prior relationally similar example in understanding the content of a later example, but they reported that they were not aware of having done so” (p.271). In another study, Schunn and Dunbar (1996) divided participants into four groups who received simulated biochemistry problems on the first day; two of the groups received problems where the solution involved inhibition and two did not. On the second day, all participants received a simulated molecular genetics problem with a solution involving inhibition. The results indicated that those who received inhibition solutions on the first day were more likely to apply an inhibition solution and solve the genetics problem correctly however these participants did not reference the biochemistry problem as a source either during problem solving or in a follow-up questionnaire. Schunn and Dunbar (1996) concluded that even in the absence of an explicit awareness of the analogical overlap between two domains, exposure to a particular target may implicitly cue or prime relevant previously encoded knowledge. “It is possible that participants ...can experience a general feeling of familiarity with the new, analogically similar situation in the absence of being able to identify why it seems familiar” (Kostic et al., 2010, p. 405).

In their experiments regarding long-term transfer, Chen et al. (2004) also found evidence for the use of source material despite a lack of conscious awareness of its application. Specifically, they found that participants who had been exposed to a folk tale containing a problem solution drawn from a particular culture (Chinese or American) produced higher rates of transfer to an analogous target problem regardless of whether they identified the folk tale as a possible source or not, in contrast to participants who had not been exposed to the story. They concluded that this finding supports both the explicit and implicit use of source analogues during problem solving. Kostic et al. (2010) propose that this may be akin to dual theories of recognition memory, where recognition is seen as occurring either on the basis of recollection (a deliberate retrieval process) or familiarity (an instinctive and often subconscious sense of recall). As indicated by Schunn and Dunbar (1996), the latter form of recognition may be primed by exposure to cues embedded within the target during encoding that the solver is not consciously aware of (Day & Goldstone, 2012; Gentner & Smith, 2013; Kokinov & Petrov, 2000; Kostic et al., 2010). The distinction between explicit and implicit transfer may also be based on the extent to which mapping is

systematic and complete as well as the scope of concept activation (Blanchette, 2000; Holyoak, 2012).

Holyoak (2012) notes that:

“...such apparently unintended transfer likely involves a different mechanism than does deliberate analogical mapping and inference...intentional relational transfer makes heavy demands on working memory and appears to be a paradigmatic example of what is sometimes termed explicit or System 2 processing... some forms of relational transfer may be more akin to priming, typically considered an example of implicit or System 1 processing...” (p. 245).

In a comprehensive overview of the current debates surrounding dual-process theories of cognition, Evans and Stanovich (2013) propose that the defining features of type one processing are that it is intuitive, autonomous in nature, and does not require working memory; in contrast type two processing does require working memory, is reflective, and involves hypothetical thinking and deliberate processing effort (termed cognitive decoupling). They also list typical correlates of both types of processing; type one processing is seen as associative, contextualised, parallel, fast, nonconscious, experience-based, and automatic whereas type two processing is seen as rule-based, abstract, serial, slow, conscious, consequential, and controlled. Despite the inherent logic of the above proposition, to date there appears to be little or no evidence regarding the implementation or consequences of different forms of analogical problem solving; and there is thus a strong need for additional research (Holyoak, 2012).

3.7. Conclusion

This chapter has outlined a range of empirical studies undertaken to identify and isolate particular process-based factors that can improve rates of analogical transfer and thus enhance schema formation and quality as well as learning. Although a large number of candidate factors have been identified, much of this work is experimental in nature, and thus subject to various methodologically-based critiques. Additional work exploring the role of contextual factors as well as the naturalistic use of analogy as a problem solving heuristic has thus also been considered, and both similarities and distinctions in findings to date described. The next chapter shifts from a consideration of process-based factors to those located within the individual, focusing specifically on the role played by individual differences in the analogical problem solving process.

Chapter 4: Individual differences in analogical problem solving

The following chapter presents a useful framework for extending the conceptualisation of factors implicated in analogical problem solving beyond those that are directly process-based. A detailed description of the theory and evidence available to date regarding the links between analogical problem solving and a range of individual difference factors is given, including general analogical reasoning capacity, intelligence, cognitive capacity, metacognitive skills, learning style preferences, expertise, creativity, motivation, and demographic characteristics. This work forms the basis for the argument underpinning the current study as well as the specific research questions posed – these are described at the end of the chapter.

4.1. Framing analogical problem solving: Barnett and Ceci's taxonomy

Transfer of learning, which occurs when any prior learning impacts on subsequent performance, not only constitutes a central aim of most educational processes, but is also intrinsically linked to both schema formation and analogical problem solving (Barnett & Ceci, 2002; Hostetter et al., 2018; Leberman, McDonald, & Doyle, 2006; Mestre, 2002b; Perkins & Salomon, 1992; Speicher & Kehrhan, 2009; Wells & Le, 2017; Wong et al., 2017). Thus, although it was originally developed as a classificatory system for organising available theory and research related to transfer of learning in the educational field, the taxonomy of far transfer developed by Barnett and Ceci (2002) is also highly relevant as a means of defining factors affecting analogical problem solving. This potential for cross-application is clearly evidenced in the fact that much of the evidence underpinning conceptualisation and development of the taxonomy was drawn from work focusing on analogical transfer.

In the taxonomy, Barnett and Ceci (2002) identify two broad categories: *content*, referring to what is transferred; and *context*, referring to when and where transfer occurs. They further divide content into: the *nature of the learned skill* (procedure, representation, or principle); the *type of performance change* to be observed (improved speed, accuracy, or approach) and the *nature of the required memory demands* (execute only, recognize and execute, or recall, recognize, and execute); and context into: the *knowledge domain*; the *physical context*; the *temporal context*; the *functional context*; the *social context*; and *modality* (each on a continuum of highly similar to highly dissimilar between the source and target problems). Furthermore, the divisions or gradations for each content and context category are subsumed within a continuum representing *near* (closely related or similar) or

far (very different or distinct) transfer (Barnett & Ceci, 2002; Billing, 2007; Chai et al., 2015; Leberman et al., 2006; Perkins & Salomon, 1992).

Barnett and Ceci (2002) note that their original intention in developing the taxonomy was to encourage classification of existing studies as representing near or far transfer along the nine dimensions, thus highlighting gaps in existing data where further research might be particularly warranted. For example, they note that much of the seminal work by Gick and Holyoak (1980) explored far transfer in terms of content but near transfer in terms of context, as it focused on transfer of a principle or heuristic, was judged in terms of accuracy and approach, and required recall, recognition, and execution of the strategy when no hint was given, but took place in the same environment and time period in the context of an experiment on an individual and verbal-written basis (although the knowledge domain did differ as the source was militaristic in nature and the target medical). Through applying the taxonomy to multiple studies, Barnett and Ceci (2002) were able to illustrate that any particular piece of empirical research tends to vary from near to far depending on which category is being considered; as a result, labelling studies as pure demonstrations of one or the other type of transfer is difficult and not necessarily desirable. In addition, they were clearly able to highlight interactions between the various facets, for example, between the type of learned skill and the nature of the required memory demands. Their analysis also highlighted the scarcity of available research on transfer across almost all of the dimensions, particularly as regards far transfer (Barnett & Ceci, 2002).

The relevance of the taxonomy for analogical problem solving is self-evident when much of the available research described earlier is considered. For example, the distinction between spontaneous and directed transfer is quintessentially one of required memory demands, specifically whether the solver need only execute the strategy (directed transfer) or must recall, recognise, and execute it (spontaneous transfer). Similarly, research exploring transfer across environments and over time clearly represents variations in physical, temporal, social, and functional contexts; and studies regarding presentation modality epitomise similarity of modality. These examples highlight the utility of the taxonomy in capturing and framing key factors that directly affect the analogical problem solving process, including domain, surface and structural similarity, transparency and concreteness, presentation milieu, memory demand, and method of assessment (Cushen, 2012; Gentner & Smith, 2012; 2013; Holyoak, 2012; Kahney, 1993; Reeves & Weisberg, 1994). Although the taxonomy is comprehensive, Barnett and Ceci (2002) note that in its proposed form it does not account for two critical sets of factors that might also play a role in delineating the analogical process and optimising transfer, namely: development and

adaptation of instructional mechanisms; and individual characteristics of the learner. Details related to the former are described earlier in this review; an extensive discussion of the latter follows.

4.2. Analogical problem solving: Individual differences

“...Models of APS should... present not only an explanation of the general processes underlying analogical reasoning, but also consider issues concerning the actual implementation of such processes by the human mind” (Antonietti & Gioletta, 1995, p. 619).

To date, much of the available research that explores topics related to analogical problem solving has focused on establishing whether and to what extent various aspects of problem presentation influence the solution process as well as methods that might be effective in enhancing transfer. It is, however, critical to acknowledge that *“... a combination of aptitudes, experiences, or abilities in conjunction with characteristics of the task at hand... contribute to success in... analogical problem solving”* (Corkill & Fager, 1995, p. 183). In order to gain a clear, comprehensive, and holistic theoretical and pragmatic understanding of analogical problem solving as a complex phenomenon, it is thus equally important to consider the potential influence of individually-based factors possessed by the problem solver (Barnett & Ceci, 2002; Corkill & Fager, 1995).

Individual differences is a categorical label used to refer to groupings of variables that represent possible sources of differential functioning based within the individual (cf., for example, Antonietti & Gioletta, 1995; Chronicle, MacGregor, Lee, Ormerod, & Hughes, 2008; Corkill & Fager, 1995; Jonassen, 2000; Ma, 2002; Woo Sohn, Doane, & Garrison, 2006). Different clusters include but are not necessarily limited to: demographic (and typically immutable) aspects, for example age, gender, language, cultural and ethnic background, schooling, and historical socioeconomic status; cognitive aspects, such as intelligence, general processing ability, higher order cognitive functioning, and memory; metacognitive aspects, such as metacognitive awareness, knowledge, and strategies for carrying out performance; motivational and affective aspects, such as levels of intrinsic and extrinsic motivation, anxiety, self-efficacy, interest, mindset, and emotional and mood state; and epistemological factors, such as level of familiarity with and expertise within the relevant field/s, and approach and heuristic preferences (Billing, 2007; Condell et al., 2010; Dermitzaki, Leondari, & Goudas, 2009; Izsof Jurasova et al., 2014; Jonassen, 2000; Kubricht et al., 2017; Mayer, 1998; Metallidou & Platsidou, 2008; Pretz et al., 2003; Schiano et al., 1989). These factors interact with each other and with factors intrinsic to the problem itself,

as well as with the broader problem solving context, to affect performance, and, specifically in the case of analogical problem solving, successful transfer.

Despite this, relatively little attention has been paid to the role that characteristics inherent in the problem solver might play in analogical problem solving in both theoretical and empirical terms (Antonietti & Gioletta, 1995; Corkill & Fager, 1995; Kubricht et al., 2017; Thomas, 2008). Antonietti and Gioletta (1995) note that in the majority of studies published in the field, individual differences in the samples obtained have been poorly reported with little detail provided. Furthermore, very few studies have specifically examined the impact of various individual difference factors on analogical problem solving success in adults (for example, Antonietti & Gioletta, 1995; Bernardo, 1998; Francis, 1999; Izsof Jurasova et al., 2014; Jausovec, 1993; Wakebe, Hidaka, & Watamura, 2015), and even fewer have examined the interplay between multiple individual difference factors (for example, Corkill & Fager, 1995; Cushen, 2012; Cushen & Wiley, 2018; Ma, 2002), possibly as a result of methodological constraints. There are also relatively few studies that have incorporated individual difference factors into their exploration of more process-based factors (for example, Hsu & Wedman, 1994; Kubricht et al., 2015; 2017; Novick & Holyoak, 1991). Given both the dearth of studies and the wide variation in focal areas between them, it is unsurprising that little clear evidence regarding the impact of any particular individual difference factor has emerged; it is, however, useful to consider what has been identified thus far as a basis for further development.

4.3. Different forms of analogy: Analogical reasoning and proportional analogies

Although its use as a heuristic problem solving strategy is both prevalent and of high theoretical and practical significance, it is important to acknowledge that analogy itself encompasses a wider range of possible applications (Antonietti et al., 2000; Güss & Wiley, 2007; Gentner & Smith, 2012; Holyoak, 2012; Kahney, 1993; Thomas, 2008). In essence, *analogy* refers to any circumstance where relational or structural similarities between elements in two situations are identified and compared as a basis for inference; this is done in order to utilise knowledge of one of the situations as a means of improving understanding of the other about which less is known (Chai et al., 2015; Day & Goldstone, 2012; Gentner & Smith, 2012; Harpaz-Itay, Kaniel, & Ben-Amram, 2006; Holyoak, 2012; Morrison, 2004; Thomas, 2008; Zook, 1991). Holyoak (2012) notes that “...*analogy is an inductive mechanism based on structured comparisons of mental representations. It is an important special case of role-based relational reasoning, in which inferences are generated on the basis of patterns of relational roles*” (p. 234). Other forms of relational reasoning include

language development and use, identification of perceptual similarity, and abstraction – all of which (including analogy) share as their basis the ability to recognise and flexibly deploy non-literal relational representations (Hummel & Holyoak, 2003). *Analogical reasoning* can thus be seen as a form of cognitive activity in which parallel sets of causal, explanatory, or logical relationships (rather than objects or surface features) shared between two situations, one of which is better understood than the other, are extracted and used to generate inferences to enhance insight (Corkill & Fager, 1995; Francis, 1999; Gentner & Colhoun, 2010; Holyoak, 2012; Kao, 2014; Zook, 1991).

Analogical reasoning is widely recognised as a fundamental cognitive skill that plays a critical role in learning, theory building, and problem solving; it is also seen as a valuable mechanism for promoting induction, creativity, knowledge expansion, and skills development (Antonietti et al., 2000; Bearman et al., 2002; Gentner & Kurtz, 2006; Harpaz-Itay et al., 2006; Hobeika, Diard-Detoeuf, Garcin, Levy, & Volle, 2016; Holyoak, 1984; Holyoak & Stamenković, 2018; Jones & Estes, 2015; Kostic et al., 2010; Krawczyk et al., 2004; Lipkens & Hayes, 2009; Thomas, 2008; Yanowitz, 2001). It has been identified as a key component of everyday discourse and communication, educational practice, inferential thought, scientific discovery, and decision-making (Blanchette, 2000; Gentner & Colhoun, 2010; Gentner & Smith, 2013; Hall, 1989; Kageyama et al., 2017; Kao, 2014; Kubricht et al., 2015; Lane & Schooler, 2004; Vendetti, Wu, & Holyoak, 2014b; Zook, 1991). It also underpins formal approaches in a number of theoretical fields, for example, *case-based reasoning* in artificial intelligence (cf. Aamodt & Plaza, 1994; Holyoak, 2012; Kolodner, Simpson, & Sycara-Cyranski, 1985) and *problem-based learning* (PBL) and *imitative learning* (IL) in education (cf. Mestre, 2002a; Norman & Schmidt, 1992; Robertson, 2000; Thomas, 2008). It has even been explored as a mechanism for enhancing consumer attractiveness and refining product marketing strategies (cf. Herzenstein & Hoeffler, 2016). One of the most widely recognized and important roles of analogy, however, remains its central position in shaping both the theory and psychometric measurement of human intelligence (Abdellatif et al., 2008; Embretson & Schneider, 1989; Green, Fugelsang & Dunbar, 2006; Holyoak, 1984; Hummel & Holyoak, 2003; Lipkens & Hayes, 2009; Morrison et al., 2004; Schiano et al., 1989; Spearman, 1923; 1927, as cited in Holyoak, 2012).

Researchers conducting empirical experimental studies that have focused on the use of analogy have largely employed one of two forms of measurement. These are open-ended isomorphic or homomorphic story problems that have been used to evaluate analogical problem solving and schema formation; and traditional, proportional analogies, which have been used to assess both broad analogical reasoning and intelligence (Abdellatif et al.,

2008; Goswami, 1991; Klein, 1994; Lee, 1992; Reimann & Schult, 1996; Sternberg, 1983; Zook, 1991). The latter consist of four terms where the first two terms (the domain) share a relationship that is equivalent to the relationship shared between the final two terms (the range); thus a second-order or higher order relationship logically subsumes the first-order relations that exist between the pairs. This is expressed as A is to B as C is to D ($A:B :: C:D$) (Goswami, 1991; Harpaz-Itay et al., 2006; Kahney, 1993; Lipkens & Hayes, 2009; Sternberg, 1977; Vendetti, Knowlton, & Holyoak, 2012; Vendetti et al., 2014b; Zook, 1991). Solving proportional analogy tasks typically requires identification of the final term based on exposure to the stem (the first three terms) however there are other format possibilities (for example, identification of both the C and D terms or identification of the A and D terms) (Kahney, 1993; Schiano et al., 1989). The degree of creativity and abstract relational thinking required by a given proportional analogy varies based on the semantic distance between the pairs; this is linked to the difficulty attributed to the item (Green, Kraemer, Fugelsang, Gray, & Dunbar, 2012a; Vendetti et al., 2012; Vendetti et al., 2014b).

Proportional analogies can be presented verbally in the form of words or visually in the form of geometric patterns, shapes, or figures; the latter vary based on size, position, and shading as well as element characteristics (Blanchette, 2000; Chai et al., 2015; Hobeika et al., 2016; Kahney, 1993; Mulholland, Pellegrino, & Glaser, 1980; Whitely, 1976). Successful recognition of the relations shared between verbal elements tends to rely heavily on linguistic comprehension of the vocabulary used and of associated connotations as well as general knowledge; as such, verbal analogies, although extremely common, are perceived to have a high potential for cultural specificity and bias (Alexander, Murphy, & Kulikowich, 1998; Freedle & Kostin, 1997; Kahney, 1993; Roomaney & Koch, 2013; Schiano et al., 1989). "...*In contrast, figural analogies, while serving as a measure of spatial (visualization) ability, are also commonly considered a 'knowledge-free' index of inductive reasoning ability*" (Schiano et al., 1989, p.226); although the extent to which this assumption is accurate is subject to continued investigation.

The nature of the higher-order relation linking the pairs of terms varies widely and may also play a role in determining item difficulty (Kahney, 1993). Common relational types include: cause-and-effect (one term occurs as a result of another); synonyms or antonyms (the meaning of the terms is the same or opposite); difference in degree (the terms represent variations in intensity); part-whole (one term is subsumed within the other); function (the terms are linked on the basis of purpose or role); conversion (one term can be converted into or is closely associated with the other); class member (one term represents a broader category than the other or both fall under the same broader category); property or quality

(one term possesses a characteristic represented by the other); location (the terms occur in proximity to one another); temporal order (the terms form part of a logical sequence); and representation (one term symbolises the other) (Pellegrino & Glaser, 1982; Spears, 2000; Whitely, 1976). In a study using a sample of over two hundred undergraduate students, Whitely (1976) found that different types of analogical relations were associated with different cognitive abilities, for example, opposites (antonyms) were associated with inductive ability whereas similarities (synonyms) were associated with divergent thinking and syllogistic reasoning. She concluded that “...*relational concepts influence the cognitive aptitudes which are reflected in analogy item performance*” (p.234); this suggests that the particular relational types represented within a given set of analogies may determine which unique cognitive skills that set is able to assess. Despite this, to date there appears to be very little research that has explicitly distinguished between or explored the effects of relational types within the existing literature; and the choice of items in a given measure of analogical reasoning appears to be largely arbitrary or based on convenience (Bejar, Chaffin, & Embretson, 1991; Kahney, 1993).

Excluding considerations of type, proportional analogies are broadly regarded as quintessential examples of *inductive reasoning* – using specific instances as the basis for creating a general rule or concept that can be applied to future examples of a similar nature (Alderton, Goldman, & Pellegrino, 1985; Kahney, 1993; Kao, 2014; Zook, 1991). This is closely aligned with the concept of schema formation although the scope of the induction is far more limited for proportional analogies than for longer story-based problems (Holyoak, 2012; Kahney, 1993). Proportional analogies are also seen as prototypical reasoning problems in the measurement of intelligent behaviour, particularly the measurement of *g* or *general intelligence* (Embretson & Schneider, 1989; Lipkens & Hayes, 2009; Mulholland et al., 1980; Schiano et al., 1989; Spearman, 1923; 1927, as cited in Holyoak, 2012; Sternberg, 1977). The direct association between proportional analogies and *g* has been highlighted in scaling studies examining the inter-relationships between a multitude of common cognitive tasks on ability tests – these clearly illustrate the centrality of proportional analogical tasks (verbal, numeric, and geometric) in representing the most complex and highly saturated sources of shared variance along with letter series (which are considered fundamental to the measurement of working memory) and necessary arithmetic operations (Marshalek, Lohman, & Snow, 1983; Snow, Kyllonen, & Marshalek, 1984, as cited in Carpenter, Just, & Shell, 1990).

g was first identified by Spearman (1904; 1927, as cited in Neisser et al., 1996) and refers to a common statistical factor that underpins skilled performance on a wide variety of

cognitive and intelligence test tasks (Buckhalt, 2002; Demetriou & Kazi, 2006; Gustafsson, 1984; Jensen, 1998; Neisser et al., 1996). It has been broadly defined as a:

“...very general mental capacity that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience. It is not merely book learning, a narrow academic skill, or test-taking smarts. Rather, it reflects a broader and deeper capability for comprehending our surroundings – “catching on”, “making sense” of things, or “figuring out” what to do” (Gottfredson, 1997, p. 13, as cited in Lubinski, 2004, p.97).

Although there is considerable debate regarding its precise nature, there is also an abundance of research highlighting the importance of *g* in determining multiple aspects of everyday functioning and cognitive performance (cf. Demetriou & Kazi, 2006; Gottfredson, 1997; Lubinski, 2004; Murray, McKenzie, & Murray, 2014; Reeve & Lam, 2007).

Furthermore, the Cattell-Horn-Carroll theory of cognitive abilities (CHC theory), which is currently the most comprehensive and widely accepted model of human intelligence within the literature, proposes that human abilities can be grouped within a hierarchical structure with *g* at the apex of a pyramid of increasingly refined, specific, and diverse skill sets (Deary, 2012; MacCann, Joseph, Newman, & Roberts, 2014; McGrew, 2009; Neisser et al., 1996; Schneider & Newman, 2015). This serves to highlight both the theoretical and practical importance of *g*, and thus of proportional analogies as one of the best single forms of measurement of the construct available.

In addition to induction and *g*, there are a number of other cognitive abilities that have been shown to be represented by or associated with proportional analogies. These include both crystallised and fluid intelligence (essentially the abilities to reason from previously acquired and novel information respectively); analytical thinking (the ability to identify, explain, and evaluate situational characteristics or components); creativity, particularly creative fluency (the ability to generate multiple unusual or unique perspectives or interpretations of a given situation); working memory; and academic achievement (Billing, 2007; Green, Cohen, Kim, & Gray, 2012b; Holyoak, 2012; Kao, 2014; Kubricht et al., 2015; 2017; Schiano et al., 1989; Vendetti et al., 2014b; Waltz, Lau, Grewal, & Holyoak, 2000). Evidence also suggests that greater proficiency when solving proportional analogies (and thus increased intellectual capacity) is associated with a tendency to work forwards rather than backwards (construction rather than elimination) as well as the ability to discard irrelevant information more efficiently (Marr & Sternberg, 1986; Schiano et al., 1989).

The earliest model outlining the process used when solving proportional analogies was developed by Spearman (1923, as cited in Kahney, 1993) and consisted of three stages,

namely: apprehension of experience; eduction of relations; and eduction of correlates. Sternberg (1977) utilised this as a foundation for developing an updated and expanded componential model of analogical processing that consists of six stages. The first stage, equivalent to apprehension of experience, is *encoding*, which involves representing each term and retrieving relevant associated information from long-term memory. This is followed by *inference* (equivalent to eduction of relations), where the relationship between the A and B terms (the domain) is determined; and *mapping*, which involves identifying the relationship between the A and C terms thus linking the domain and the range. In the fourth stage, *application*, which is equivalent to eduction of correlates, various options for completing the C:D relationship (the range) are tested as regards their capacity for representing an isomorphic relation to the one embodied in the domain (the A:B relationship); this is followed by the fifth stage, *justification*, in which a rationale for selection of a particular D term is developed. The final stage, *response*, covers certain preparatory steps necessary as well as presentation of the final derived solution (Kahney, 1993; Schiano et al., 1989; Sternberg, 1977; Zook, 1991). Sternberg (1977) also tested various information processing strategy models applicable to the intermediate stages (inference, mapping, and application). His results suggested that mapping and application were most likely to be self-terminating in nature (the first piece of information available in working memory is utilised to initiate the next process immediately) whereas inference appeared more exhaustive (all of the information in working memory is considered before the next process is initiated) (Kahney, 1993; Sternberg, 1977). Although Sternberg's model was critiqued and various alternates developed (cf. Heller, 1979, as cited in Kahney, 1993; Mulholland et al., 1980), it is important to recognise that these differed primarily in relation to sequencing of the component processes (particularly the intermediate stages) rather than the actual processes themselves; there is thus considerable overlap between the various models and general agreement as regards the nature of the cognitive activities engaged in during the solution process as a whole (Kahney, 1993; Zook, 1991).

4.4. Analogical problem solving and analogical reasoning

Although they are recognised as assessing distinct manifest phenomena, it is widely assumed that performance on proportional analogy tasks and isomorphic story tasks stems from the same latent cognitive skill set; and that both represent forms of measurement of the same underlying ability. As a result, there is also a tendency to regard both analogical reasoning and analogical problem solving as instances of a single construct, namely a broad capacity to utilise analogy successfully (cf. Abdellatif et al., 2008; Embretson & Schneider, 1989; Goswami, 1991; Holyoak, 1984; Kahney, 1993; Morrison, 2004; Zook, 1991). It is

important to note, however, that “...traditionally, these two research strands [analogical reasoning and analogical problem solving] have been investigated separately, with little cross-talk between them” (Kahney, 1993, p. 105); thus the assumption of a common origin and the nature of the relationship between the two is not one that has been explored extensively (Holyoak, 1984; Kubricht et al., 2015; 2017; Novick & Holyoak, 1991). Furthermore, the relatively small amount of empirical evidence that is available is somewhat contradictory.

In a study that was focused primarily on establishing the effects of different types of mapping hints as well as solution adaptation, Novick and Holyoak (1991) also explored whether transfer between several isomorphic mathematical problems in a sample of a hundred and thirty-two undergraduate university students could be predicted by general analogical reasoning ability. They assessed the latter using the verbal analogy section of the Differential Aptitude Tests (DAT), which consists of fifty multiple-choice format proportional analogies in which only the second and third (B and C) terms are given; respondents are then required to select the most appropriate first and fourth terms (A and D) from five options. In their analysis, they identified a non-significant weak relationship ($r = 0.15$) between performance on the verbal analogies test and analogical transfer; and further suggested that analogical reasoning ability did not predict analogical problem solving performance (Novick & Holyoak, 1991). Jausovec (1993), as part of a larger study exploring the effects of metacognitive training, conducted an experiment which examined whether intellectual giftedness led to differences in analogical problem solving performance using Duncker’s radiation problem as the target. Twenty participants were designated as intellectually gifted on the basis of high scores on intelligence tests or measures of artistic creativity as well as exceptional scholastic achievement; and their performance was compared to a control group of sixteen average students. The results indicated that there were no significant differences in transfer performance (the number of analogical solutions produced) between the two groups.

In another experiment, Antonietti and Gioletta (1995) assessed the relationship between analogical problem solving (with Duncker’s radiation problem as the target) and analogical reasoning in a sample of forty-three undergraduate students using the Raven’s Standard Progressive Matrices (RSPM) as their measure of analogical reasoning. The RSPM, which are non-verbal in nature, consist of five sets of twelve multiple choice questions (sixty in total), each of which begins with a three-by-three grid in which eight blocks are complete. Respondents are required to induce the pattern or sequence represented in these blocks through assessing changes in the number, shape, size,

orientation, shading, or other aspects of the various elements given; and must then select the option they feel best fits into the blank ninth block in the grid to complete the pattern or sequence (Alderton & Larson, 1990; Bors & Stokes, 1998; Brouwers, Van de Vijver, & Van Hemert, 2009; Carpenter et al., 1990; Meo, Roberts, & Marucci, 2007; Raven, 2000). As a result of the almost purely visual nature of the task, the RSPM are widely regarded as a culture-reduced test that can be applied fairly to different populations without raising substantive concerns of linguistic, cultural, and educational bias (although the extent to which this is an accurate assumption is subject to continued investigation and debate); in contrast to verbal measures of analogical reasoning which depend heavily on crystallised knowledge (Brouwers et al., 2009; Fox & Mitchum, 2013; Kahney, 1993; Paul, 1985; Raven, 2000; Raven, Raven, & Court, 1998; Rushton, Skuy, & Bons, 2004). Despite the shift to a non-verbal measure, the results obtained continued to indicate that there was no significant relationship between analogical reasoning and analogical problem solving – instead the pattern of findings suggested nearly equal numbers of analogical problem solvers between the high and low analogical reasoning ability groups. Antonietti and Gioletta (1995) argued that their findings, when considered in conjunction with those of Novick and Holyoak (1991) and Jausovec (1993), provided relatively convincing evidence that no relationship exists between analogical problem solving ability and intellectual capacity as assessed through verbal and visual analogical reasoning as well as giftedness.

Although the reasons for the lack of a significant empirical relationship between analogical problem solving and analogical reasoning in the studies cited above are not clear, a number of possible explanations have been proposed. One set of concerns that has been raised are technical in nature and question aspects of the instrumentation and methods used. These include the possibility of confounding when more than one independent variable was assessed; the extent to which verbal measures of analogical reasoning would logically be expected to play a role in predicting mathematical performance; the possibility of ceiling effects having occurred on certain of the measures (especially the RSPM) due to the highly proficient nature of the samples; and the extent to which the differences in the tasks posed may have evoked discrepant attitudes, emotions, and motivational orientations among participants while under observation (Antonietti & Gioletta, 1995; Corkill & Fager, 1995; Novick & Holyoak, 1991). Other possibilities raised are more theoretical in nature, and relate to differences in conceptualisation, structure, and scope between the constructs which suggest that although the two resemble one another superficially, there are also critical disparities between them (Goswami, 1991; Holyoak, 1984; Kahney, 1993).

In addition to containing far less general content and no extraneous content, proportional analogies are also typically more restricted, artificial, and defined than analogical problem solving tasks; the latter tend to depict more realistic and complex situations that subsume a much wider range of relations and elements than the former (Holyoak, 2012; Kahney, 1993; Lee, 1992). The nature of the relations between the elements also varies between the two tasks – for proportional analogies these tend to be relatively simplistic, based on shared attributes or features, and somewhat arbitrary, whereas for analogical problem solving tasks these tend to be causal in nature, more elaborate, and carefully aligned (Goswami, 1991; Holyoak, 1984). Goswami (1991) notes that problem isomorphs involve comparing only two elements (a single source with a single target) whereas proportional analogies involve comparing four elements (within the domain and the range as well as between them) thus although the relations inherent in proportional analogies may be simpler, there are more of them to consider and they typically span both lower and higher order relations. There is however a greater degree of flexibility for inference in proportional analogies, in that either the range or the domain can be used to develop an understanding of the shared underlying relations, whereas in analogical problem solving tasks the given target must be solved through identification (recognition) of an appropriate source (Holyoak, 1984).

Both Goswami (1991) and Holyoak (1984) note that solving proportional analogies and solving isomorphic story problems are functionally different in that the purpose of the former is both obvious and contained (the intention is clearly to utilise the given information to develop a solution that completes the pattern) whereas the purpose of the latter is far broader and more open-ended (to solve the problem presented). As such, successfully completing an isomorphic story problem task may not require any form of analogical thought (unlike proportional analogies where analogical reasoning is mandatory) and, in as far as solving through analogy may be applied, this further requires identifying and retrieving an appropriate base analogue that is not an intrinsic component of the question posed (Antonietti & Gioletta, 1995; Antonietti et al., 2000; Goswami, 1991; Holyoak, 1984; Kubricht et al., 2017). This points to another critical distinction between the two tasks in terms of the range of skills they draw on and their scope. Whereas identification and activation of an appropriate source are key component processes within successful analogical problem solving (particularly spontaneous transfer), within proportional analogies all necessary information is directly provided and thus issues surrounding recognition of structural similarity between the two domains are largely avoided (Holyoak, 1984; Kahney, 1993; Kubricht et al., 2015; 2017; Lee, 1992). Gick and Holyoak (1983) note that “...a major limitation is that such stimuli [proportional analogies] obviate any need for the subject to

spontaneously notice the analogy, which is often a prerequisite for successful transfer in realistic problem situations” (p.3).

This absence highlights fundamental differences “...*in the amount of cognitive processing required to solve complex problems...as opposed to simple...analogy problems”* (Kahney, 1993, p.140). Although there is a degree of overlap in the various process models proposed (for example, both sets of models prioritise mapping and adaptation), there are also key differences as regards the number, complexity, and sequencing of the various component processes between analogical reasoning and analogical problem solving that emphasise the greater difficulty of the latter (Antonietti & Gioletta, 1995; Holyoak, 1984; Novick & Holyoak, 1991). These variations are sufficiently distinct for Holyoak (1984) to argue that “...*the conception of analogy that has emerged from work on problem-solving is substantially different from that reflected in models based on studies of proportional analogy problems”* (p.224); and Goswami (1991) conceded that the two tasks might in fact be measuring different skill sets altogether. Novick and Holyoak (1991) identified four criteria they felt reflected “...*differences between the apparent requirements for success on the psychometric items versus analogical transfer”* (p. 412), namely: the need to retrieve a source; the types of knowledge required for success; the inherent difficulty of the mapping process; and the inherent difficulty of the adaptation process. They also argued that the differences in the types of knowledge and adaptation processes required were the most relevant in accounting for the lack of a significant relationship between analogical reasoning and analogical problem solving.

Although the technical and conceptual arguments outlined above are compelling, there nevertheless remains an intuitive expectation that there would be a degree of overlap or association between two forms of measurement that are both widely regarded as assessing the ability to think and reason analogically (Antonietti, 1996; Goswami, 1991; Holyoak, 1984; Novick & Holyoak, 1991).

“...I have emphasized [sic] the differences between analogical problem solving and solving analogy items, but I do not mean to imply that the two types of tasks are entirely unrelated. On the contrary, I would expect to find a substantial positive relationship between the ability to solve problems by analogy and standard measures of analogical reasoning (a worthwhile direction for future research)” (Holyoak, 1984, p.225).

Despite substantial differences between the tasks as regards scope, both traditional proportional analogies and isomorphic story problems can be expressed using the same

basic configuration (problem_{source}: solution_{source} :: problem_{target}: solution_{target}). In addition, successful resolution of both tasks relies on effective inference of the shared relational structure; and thus there is considerable overlap as regards the core component processes (representation, mapping (structural identification and comparison), and adaptation) employed (Gentner & Markman, 1997; Holyoak, 1984; Kahney, 1993; Lee, 1992; Zook, 1991). Corkill and Fager (1995) suggest that individuals with greater skill in effectively deploying these component capabilities may also be more proficient in accessing and manipulating information stored in both long-term and working memory; thus proposing a link between these abilities and analogical reasoning adeptness. There is also an established relationship between intelligence (including analogical reasoning proficiency) and general problem solving ability, possibly as a result of an enhanced capacity for knowledge acquisition and strategic utilisation associated with the former (Cho, 2010; Holyoak, 1984; Kahney, 1993). This is supported by research which suggests that children with greater intellectual capacity are more likely to infer, transfer, and flexibly deploy strategies acquired during learning (Campione, Brown, Ferrara, Jones, & Steinberg, 1985; Cho, 2010; Ferretti & Butterfield, 1992; Kahney, 1993). Research has also shown that those with higher intelligence tend to be more proficient in selectively and successfully implementing various information-based sub-processes such as encoding and comparison, suggesting that those with higher intelligence could reasonably be expected to enact analogical transfer more effectively (Corkill & Fager, 1995; Gorodetsky & Klavir, 2003; Kubricht et al., 2017; Neisser et al., 1996; Novick & Holyoak, 1991).

These findings align with the argument set out by Holyoak (1984), who suggests that aptitude within all forms of analogical thinking and reasoning may stem from a shared source, specifically a broad set of abilities reflecting one's individual capacity for effectively dealing with and manipulating information; and further indicates that this would link closely to the cognitive skill sets that underpin intelligent behaviour. This is essentially the same argument as that proposed by Barnett and Ceci (2002), who assert that transfer of learning (including analogical transfer) and its component skills not only play a substantive role in determining intelligent behaviour, but are also highly likely to be "...*influenced by individual differences in general cognitive capacities and other aspects of general intelligence that operate independently of the influence of context, as well as by aspects of the context and content*" (p. 633). They also note that the role played by these general skills in determining analogical transfer may vary based on (in other words, be moderated by) a variety of other factors. They further contend that "...*we might expect variations in general intelligence to be intimately linked to success at transfer...*" (Barnett & Ceci, 2002, p.633), thus strongly

supporting the existence of a potential positive relationship between analogical reasoning and analogical problem solving.

Although largely speculative in nature, a degree of possible evidentiary support for this argument can be drawn from neuropsychological research exploring which areas of the brain are activated during analogical and relational reasoning. Findings across a range of functional magnetic resonance imaging (fMRI) studies converge to support the critical role of the prefrontal cortex, particularly the left rostrolateral (frontopolar) region, when solving four-term proportional analogies or making judgements regarding relational similarity (cf. Bunge, Wendelken, Badre, & Wagner, 2005; Gentner & Smith, 2012; 2013; Green et al., 2012a; Hobeika et al., 2016; Holyoak, 2012; Krawczyk, McClelland, Donovan, Tillman, & Maguire, 2010; Morrison et al., 2004; Vendetti et al., 2012; Vendetti et al., 2014b; Whitaker, Vendetti, Wendelken, & Bunge, 2017). The prefrontal cortex controls executive functioning, and is implicated in moderating behaviour and planning, learning, fluid intelligence, controlled semantic retrieval, and working memory (Holyoak, 2012; Miller, Freedman, & Wallis, 2002; Whitaker et al., 2017). Additional areas activated during analogical reasoning have been linked to the representation and storage of knowledge and include the hippocampus, the anterior temporal cortex, the inferior and middle frontal gyri, and the parietal cortex (Hobeika et al., 2016; Holyoak, 2012; Kolb & Whishaw, 2009). In contrast to analogical reasoning, there are almost no studies available that have explored brain activation during analogical problem solving (Gentner & Smith, 2013). Lee, Fincham, Betts, and Anderson (2014), however, did explore patterns of brain activation when participants who had received instruction regarding solving algebraic-type problems attempted to transfer the solution strategies learnt to other problems of a similar type. Their data identified an association between successful transfer and activation of the prefrontal cortex, particularly the right rostrolateral region. Although highly preliminary, this partial similarity in areas of activation could be seen to give some support to the notion of a common set of component skills underpinning effective analogical performance across reasoning and problem solving tasks.

More directly, and in contrast to the empirical findings of Novick and Holyoak (1991), Jausovec (1993), and Antonietti and Gioletta (1995), there are some studies that have identified a significant empirical relationship between analogical reasoning and analogical problem solving. Corkill and Fager (1995) explored whether several individual difference variables, including familiarity, creativity, deductive ability, and verbal ability, predicted both spontaneous and directed transfer between various isomorphic versions of problems that could be solved using the convergence schema. Their sample consisted of one hundred and sixteen psychology undergraduate students as well as sixty-five high school seniors and,

similarly to Novick and Holyoak (1991), their measure of verbal ability was the verbal analogies section of the Differential Aptitude Tests. Unlike Novick and Holyoak (1991), however, Corkill and Fager (1995) found that verbal analogical reasoning ability was a significant predictor of both spontaneous analogical transfer overall and for transfer between isomorphs that were both categorised as less familiar to the participants (the radiation problem and the lightbulb problem). In another study, Ma (2002) explored whether analogical transfer was associated with both intellectual ability and cognitive style; and found that solvers with higher levels of intellectual ability tended to map at a more structural level and transferred more frequently and successfully. Klein (1994), in contrast to Jausovec (1993), found that more academically talented junior high school students (Honours students) provided with a single source analogue of the convergence schema produced a significantly higher rate of analogical transfer than less talented students (regular students), although this effect was removed when two source analogues from different content areas were provided. Her results also indicated that the Honours students in her sample reported a greater tendency to relate the target task to previously known content.

Vendetti et al. (2014b) examined the extent to which two forms of relational priming (evaluation and solution generation) could create a frame of mind in which relationally-based correspondences would be preferred to surface or featurally-based matches in a picture-mapping task carried out by college undergraduates. As part of the study, they assessed participants' analogical reasoning capacity (as representative of fluid intelligence) using a shortened version of the Raven's Advanced Progressive Matrices (RAPM). The RAPM, which consist of an initial set of twelve items for practice followed by a second set of thirty-six items, are similar in format to the RSPM but are designed to account for ceiling effects identified among high-scoring respondents on the latter. As such, the RAPM are intended for use in groups that typically evidence superior intellectual performance, and distinguish between performers who score in the top twenty-five percent of the RSPM (Bors & Stokes, 1998; Meo et al., 2007; Mills & Ablard, 1993; Paul, 1985; Raven, 2000; Raven et al., 1998; Spreen & Strauss, 1998). During analysis of their results, Vendetti et al. (2014b) "...found that generating (but not evaluating) solutions for semantically distant analogies increased the proportion of relational mappings on the transfer task" (p.1). They also identified a significant, positive relationship ($r = 0.41$) between performance on the abridged version of the RAPM (representing fluid intelligence) and relational responses for participants who self-generated solutions to near analogy problems (but not for far analogy problems or overall). In another study examining the effects of including animation during presentation of the source on spontaneous transfer of the convergence schema, Kubricht et al. (2015) also explored whether this effect differed on the basis of levels of fluid intelligence (as assessed

by an abridged version of the RPM). Although they did not report results regarding the relationship between analogical reasoning (fluid intelligence) and spontaneous transfer directly, they did identify differences in rates of transfer between the various groups (verbal presentation only, verbal presentation and a diagram, verbal presentation and an animation) on the basis of high or low performance on the shortened RPM. This analysis indicated that for those with a high level of fluid intelligence, solution rates between the groups did not differ significantly; however, for those with a lower level of fluid intelligence, presentation of the source with an animation substantially improved rates of spontaneous transfer (approximately seventy-eight percent compared to approximately forty and thirty-three percent in the other groups). This pattern suggests that analogical reasoning ability, as indicated by performance on the abridged RPM, might interact with other determinants such as presentation format to affect analogical transfer and problem solving, a proposition in line with that of Barnett and Ceci (2002) regarding moderation.

In a follow-up study, Kubricht et al. (2017) created a moderated mediation model using data from two-hundred-and-four undergraduate college student participants. Their model included fluid intelligence as a proposed independent variable (measured using an abridged twelve-item version of the RPM and thus also representing analogical reasoning), source understanding as a proposed mediator, rate of spontaneous transfer for the convergence solution as the proposed dependent variable, and provision of supplemental animation as the proposed moderator. Their findings supported all of these hypotheses, suggesting that fluid intelligence directly predicted rate of spontaneous transfer, that this relationship was fully mediated by source comprehension, and that the mediation model was moderated by animation (Kubricht et al., 2017). They argue that, to the best of their knowledge, their work provides “...*the first demonstration that fluid intelligence is a predictor of spontaneous analogical transfer*” (Kubricht et al., 2017, p.585), thus providing direct evidence for an empirical relationship between analogical reasoning and analogical problem solving.

From the above discussion, it is clear that there are both conflicting theoretical understandings and contradictory empirical findings regarding the nature of the relationship between analogical reasoning and analogical problem solving. The situation is further complicated by the propensity prevalent in much of the available literature for the two concepts to be treated interchangeably; leading to a tendency to amalgamate or condense information relevant to either phenomenon (cf. Abdellatif et al., 2008; Embretson & Schneider, 1989; Goswami, 1991; Kahney, 1993; Morrison, 2004; Zook, 1991). The precise nature of the association between analogical problem solving and various forms of

intelligence, *g*, and analogical reasoning skills thus remains an open question and further research (particularly of a form that addresses methodological concerns raised in previous accounts) is patently warranted.

4.5. Other cognitive factors

To date, there appears to be minimal research that explores the relationship between analogical problem solving and cognitive factors other than intelligence, *g*, and analogical reasoning in adults. One of the few exceptions to this is work by Corkill and Fager (1995), who examined whether deductive reasoning skill predicted transfer between various isomorphs of the convergence schema. *Deductive reasoning* or logic refers to a process of analysis in which premises or hypotheses (in problems, these are often given as clues) that are taken as true are used as the basis from which to develop logical conclusions or solutions to a given situation or problem (Corkill & Fager, 1995; Pillow, 2002; Prado, Chadha, & Booth, 2011; Sternberg, 2009). In their study, Corkill and Fager (1995) obtained a sample of one hundred and eighty-one participants (high school seniors and university undergraduates) who completed both the analogical problem solving exercise and a deductive logic problem in which the full name of the owner and type of business for four shops had to be identified from clues given. The results indicated that success on the deductive reasoning task was a significant predictor of both spontaneous and directed analogical transfer overall as well as for directed transfer between a less familiar source (the radiation problem) and a more familiar target (the firefighter isomorph). Corkill and Fager (1995) had expected a relationship between deductive reasoning and directed transfer as the latter typically involves application of a solution derived from a known source or schema (which would constitute the initial set of premises or hypotheses). The role of deductive reasoning in predicting spontaneous transfer was less anticipated; however Corkill and Fager (1995) did suggest that transfer typically involves both inductive and deductive thinking.

Another relevant study was conducted by Cushen (2012), who explored the extent to which composite measures of *focused and diffuse attention* (derived from measures of divergent thinking, working memory capacity, inhibition, susceptibility to distraction, and attentional flexibility) could be used to predict spontaneous and directed transfer between the lightbulb isomorph as the source and Duncker's radiation problem as the target. He also examined the relationship between spontaneous transfer and representational quality (general quality and quality of the convergence schema). His final sample consisted of one hundred and twenty undergraduate students from the University of Illinois in Chicago, sixty-

two percent of whom were female. The results obtained indicated that both focused and diffuse attention contributed unique variance when predicting spontaneous transfer as well as directed transfer; and representational quality significantly predicted spontaneous transfer however schema quality (of the convergence schema) did not.

As part of the rationale underpinning his study, Cushen (2012) cited research supporting a link between increased executive control (which includes abilities associated with regulating and directing attention and distinguishing relevance of information) and general problem solving success. He also reported on findings that have shown a direct relationship between executive functioning (including focused attention) and abilities such as coping with relational complexity, avoiding distraction, and recognising structural similarity, all key aspects of analogical reasoning (cf. Cho, Holyoak, & Cannon, 2007; Cushen, 2012; Cushen & Wiley, 2018; Morrison, 2004; Morrison et al., 2004; Richland et al., 2010; Viskontas, Morrison, Holyoak, Hummel, & Knowlton, 2004). Given this, as well as the relationship established between focused attention and representational quality within his study, Cushen (2012) argued that it was expected that focused attention would act as a substantive predictor of analogical transfer. He also argued that diffuse attention (in the form of a broad memory search) would enhance identification of non-obvious relationships and could partly represent the ability to employ crystallised intelligence during transfer activity, hence its role as an additional predictor was logical.

In another study focused on attention, Storm and Bui (2016) examined the effect of mind-wandering (focusing on thoughts other than those directly linked to the task at hand) on transfer performance when solving Duncker's radiation problem. Their sample consisted of a hundred and two undergraduate students from the University of California, Santa Cruz. Contrary to the proposition that mind-wandering would enhance opportunities for creative and original relational thought, the results indicated that it tended to worsen transfer performance, possibly as a result of impaired encoding.

Although these studies provide a degree of preliminary support for the role of attentional control in analogical problem solving, and despite its close association with working memory (cf. Cushen, 2012; Cushen & Wiley, 2018), to date there appear to be a very limited number of studies that have directly explored the nature of the relationship between working memory capacity and analogical problem solving in an adult sample. This is somewhat surprising given the vast body of empirical findings that clearly indicate that working memory capacity is strongly associated with various aspects of intelligence, including both fluid intelligence and analogical reasoning (as assessed by traditional

proportional analogy tasks and relational mapping tasks) (cf. Bühner, Kröner, & Ziegler, 2008; Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004; Kane et al., 2004; Kyllonen & Christal, 1990; Oberauer, Süb, Wilhelm, & Wittmann, 2008; Shipstead, Lindsey, Marshall, & Engle, 2014; Simms, Frausel, & Richland, 2018; Süb, Oberauer, Wittmann, Wilhelm, & Schulze, 2002; Unsworth, Fukuda, Awh, & Vogel, 2014). Working memory capacity has also been linked with increased skill in relational representation and integration, heightened interference resolution, superior inference generation, improved comprehension, enhanced creativity, and a greater capacity for learning, all of which could logically be expected to link to successful analogical thinking (Cho et al., 2007; Cushen, 2012; Ferretti & Butterfield, 1992; Holyoak, 2012; Krawczyk et al., 2004; Lee & Therriault, 2013; Richland et al., 2010).

Working memory is a multi-faceted construct that refers to the finite memory system available for temporarily holding and manipulating verbal or non-verbal information retrieved from either long-term memory or sensory input (Alloway, 2006; Alloway, Gathercole, & Pickering, 2006; Baddeley, 1997; 2012; Süb et al., 2002). In line with a number of multi-componential models proposed, it is widely accepted that processing of the content of this information is divided between the phonological loop (which deals with verbal and numerical content) and the visuospatial sketchpad (which deals with visual and spatial content) (Alloway et al., 2006; Baddeley, 1997; 2012; Süb et al., 2002). There are also two primary functions of working memory that have been proposed, namely simultaneous storage and processing, which refers to deriving, transforming, and retaining information, and relational integration or coordination, which refers to perceiving relations and creating relational structures or representations (Baddeley, 2012; Buehner, Krumm, & Pick, 2005; Bühner et al., 2008; Oberauer et al., 2008; Süb et al., 2002). The latter function, in particular, highlights the potentially critical role of working memory during analogical transfer.

Working memory capacity determines the amount of information that can be maintained and processed at a given point in time; although even for highly adept individuals this amount is relatively restricted (Alloway, 2006; Baddeley, 2000; 2012; Day & Goldstone, 2012; Krawczyk et al., 2004). "*Previous research...suggests that analogical reasoning is a computationally intensive process that makes strong demands on working memory*" (Markman et al., 2007, p. 1105). Additional evidence also indicates that there is a tendency for individuals to shift attention from relational to surface features and become more easily distracted by irrelevant information as memory load increases (Bassok, 2003; Day & Goldstone, 2012; Francis, 1999; Markman et al., 2007; Richland & McDonough, 2010; Waltz et al., 2000). Working memory capacity may thus play a crucial role in determining the extent

to which successful analogical transfer of a given problem solution may occur, particularly spontaneous transfer. An additional degree of support for this proposition can be inferred from findings cited previously regarding methods of schema enhancement as many of these (for example, cueing, removal of irrelevant content, and balancing between presentation modalities) also function as methods of cognitive load reduction (cf. Day & Goldstone, 2012; Renkl & Atkinson, 2003).

Given the dearth of empirical evidence available, it is evident that further research to establish the nature of the relationship between working memory and analogical problem solving, as well as the extent to which additional methods of cognitive load reduction can enhance transfer success, is highly warranted; as is additional research regarding the role of attention. As Cushen (2012) notes “...*understanding of the influence of individual differences in attention across the transfer process and within many of its component processes is still lacking*” (p.7); this similarly applies to almost all cognitive-based sources of individual difference.

4.6. Metacognition

Metacognition, essentially “...*thinking about one’s own thinking*” (Güss & Wiley, 2007, p.1), refers to an individual’s cognisance and understanding of and capacity to monitor and adapt their own cognitive processes and task performance (Antonietti et al., 2000; Billing, 2007; Jonassen, 2000; Metallidou & Platsidou, 2008; Schraw & Dennison, 1994). It encompasses awareness of one’s own abilities, intellectual resources, and strategy preferences and choices (declarative knowledge); as well as knowledge of when, how, and why to apply these (procedural and conditional knowledge). It also incorporates a variety of skills related to understanding and regulation of cognition, including: planning; comprehension monitoring; information management (including organisation, selective focus, and elaboration); debugging (performance correction); knowledge re-structuring; reflection; and evaluation (Antonietti et al., 2000; Billing, 2007; Güss & Wiley, 2007; Jonassen, 2000; Metallidou & Platsidou, 2008; Schraw & Dennison, 1994). Both increased metacognitive skills and enhanced metacognitive awareness have been associated with improved learning performance, conceptualisation, and knowledge integration; and both are considered critical elements of complex problem solving, particularly for ill-defined problems (Billing, 2007; Dermitzaki et al., 2009; Güss & Wiley, 2007; Mayer, 1998). This is because metacognitive practices promote greater self-reflection and self-awareness, optimal strategy choice and implementation, and improved resource allocation; all of which play a key role in

successful problem solving (Antonietti et al., 2000; Dermitzaki et al., 2009; Güss & Wiley, 2007; Jonassen, 2000; Wedman et al., 1999).

There is a fair amount of research available in which relationships between analogical problem solving and different aspects of metacognition have been investigated. In one study, Klein (1994) explored transfer between various isomorphs of the convergence solution in a sample of junior high school students on the basis of several variables, including metacognitive strategy use (assessed on a five-item measure adapted from the Self-Assessment Questionnaire). Her results showed a direct relationship between higher rates of spontaneous analogical transfer and increased metacognitive strategy use (selection and organisation of information and strategic approach). In contrast, Gary, Wood, and Pillinger (2012) explored transfer between novel source and target problems related to strategic decision-making in management scenarios in a sample of university students studying business. They examined metacognitive activity as one of several control variables using a five-item measure of self-reported engagement in planning, monitoring, evaluation, and revision during encoding of the source. Their results indicated that there was no significant relationship between metacognitive activity and performance on the target task; although increased metacognitive activity was associated with significantly better source task performance.

Similarly contradictory patterns of findings have been seen in studies examining the effect of metacognitive training. For example, Jausovec (1993) conducted experiments in which two different training methods designed to improve metacognition (one more general, one specifically geared towards analogical reasoning) were provided to participants in an attempt to discover whether this facilitated analogical problem solving or not. The results indicated that neither training method was successful (although it is worth noting that the sample sizes were very small). In contrast, Muldner and Conati (2010) were able to enhance analogical problem solving success through fostering metacognitive behaviours associated with effective example-based learning using an adaptive intelligent tutoring system (the Example Analogy Coach). In another study, Haynie, Gregoire, and Shepherd (2004) were able to demonstrate that training to increase both metacognitive awareness and analogical problem solving improved strategic decision-making in an organisational context and, most relevantly, also showed that the degree to which analogical training was useful in this regard was moderated by level of metacognitive awareness.

Although there is a degree of contradiction within the evidence that is available, it is important to note that the source of many of these inconsistencies may lie in discrepant

definitions or operationalisations of the concept of metacognition itself. Due to its broad nature and highly variant composite behaviours, there is little alignment between studies regarding the precise specifications and measurements used. Despite this, when considered holistically and in conjunction with theoretical understandings of metacognitive concepts, the balance of material available appears to suggest that metacognition plays a primarily positive role in facilitating transfer and analogical problem solving (Barnett & Ceci, 2002). However, further research to establish whether this is in fact the case, and particularly sets of studies in which metacognition is assessed using the same underlying conceptualisation, are necessary; as are studies exploring the application of metacognitive skills within different occupational and educational settings and across different cultures (Antonietti et al., 2000; Güss & Wiley, 2007).

4.7. Cognitive learning styles

Cognitive learning styles, which can be seen as distinct and individual patterns of information assimilation and processing, are among those components that metacognition promotes awareness and skilled application of. McLoughlin (1999) defines cognitive learning styles as “...*habitual ... and systematic modes of acquiringorganising, and processing information*” (p.224). Similarly to metacognition, the concept is a multi-faceted one that encompasses classifications based on either broad approach or specific practice drawn from cognition, personality, and action/ behaviour; and there are numerous models available which present highly variant demarcations of the broader construct (Busato, Prins, Elshout, & Hamaker, 2000; Cano-García & Hughes, 2000; Coffield, Moseley, Hall, & Ecclestone, 2004; Jeffrey, 2009; Pashler, McDaniel, Rohrer, & Bjork, 2008; Rayner & Riding, 1997). Despite this diversity, there is a presumption that relationships between various conceptualisations of cognitive learning style and problem solving success exist; as it is likely that “...*learning styles are related to the selection process of strategies for handling new situations, as in the case with problem solving*” (Metallidou & Platsidou, 2008, p.115).

Antonietti and Gioletta (1995) conducted a series of studies in which they explored the nature of the relationships between various cognitive learning style models and successful analogical problem solving. The latter was assessed based on transfer between Duncker's radiation problem as the target and an isomorphic source for the convergence schema (the artificial lake). Their learning style models included left style-right style thinking (measured using the Style of Learning and Thinking questionnaire), visual-verbal thinking (measured using the Visual-Verbal Strategies questionnaire), adaption-innovation (measured using the Kirton Adaption-Innovation Inventory), and field in/dependence (measured using the Group

Embedded Figure Test). Their samples consisted of undergraduate university students from different disciplines who volunteered to take part and ranged in size from fifty to seventy-five participants per study.

Left style thinking as conceptualised in the SOLAT model refers to a preference for verbal, analytical, abstract, and logical reasoning, in contrast to *right style thinking* which is non-verbal, holistic, concrete, and synthetic (Al-Sabaty & Davis, 1989; Antonietti & Gioletta, 1995; Torrance & Rockenstein, 1988). This overlaps quite strongly with the visual-verbal distinction proposed by Richardson (1977), which refers to a preference for linguistic representation or verbal imaging during processing. Antonietti and Gioletta (1995) proposed that successful analogical transfer would be associated with a preference for right style thinking and visualisation based on their role in supporting the effective use of imagery while solving the radiation problem which has visuospatial elements (Kubricht et al., 2015; 2017; Pedone et al., 2001). However their findings indicated that there were no significant relationships between analogical problem solving and left style thinking, right style thinking, visualisation tendency, or verbalisation tendency in their sample. Antonietti and Gioletta (1995) argued that this may have been due to an inability to distinguish the roles played by the various preferences given that they all could be utilised or possibly even required while solving analogically. Using the adaption-innovation model proposed by Kirton (1976) as a basis, Antonietti and Gioletta (1995) also proposed that *adaptors*, who prefer continuity and seek to utilise well-tried solutions, would have a greater tendency to solve problems analogically in comparison to *innovators*, who prefer novel approaches and query previous assumptions. Their findings did not show a significant relationship between either an adaptor or an innovator approach and analogical transfer; they did, however, note a higher frequency of analogical solutions from adaptors. Ma (2002) utilised a similar framework (assimilator versus explorer) but findings indicated the opposite pattern; more effective structure mapping, associated with better analogical problem solving performance, was employed more frequently by explorers as opposed to assimilators.

Field in/dependence refers to one's ability to identify or disembed important elements included in complex patterns and abstract them for use (Antonietti & Gioletta, 1995; Witkin, Moore, Goodenough, & Cox, 1975; Yamazaki, 2005). This skill may play a particularly important role in facilitating appropriate structural and/or schematic representations of the core solution strategy to be transferred as field independence reflects an individual's abilities to extract only critical correspondences and to ignore surrounding irrelevant contextual or surface information (Antonietti & Gioletta, 1995; Bassok, 2003; Gentner, 1989; Jonassen, 2000; Zook, 1991). In their study, Antonietti and Gioletta (1995) found that there was a

significant relationship between field in/dependence and successful transfer; and also noted that of twenty-five participants who solved analogically, seventeen were field independent. They argued that this provided confirmation of the importance of being able to distinguish between crucial components of the solution and less relevant situational factors during analogical problem solving, particularly for cross-domain problems (Antonietti & Gioletta, 1995). Further support for this claim was obtained in a study conducted by Hsu and Wedman (1994), who established that field-independent solvers tended to perform better than field-dependent solvers, particularly if provided with multiple sources and a principle-based emphasis.

The notion that orientation towards a particular cognitive learning style or preference may aid successful analogical transfer is theoretically logical; however for the most part the empirical evidence that is available suggests few links between the two concepts (with the notable exception of field in/dependence). There are several possible explanations for this, including contradictory evidence regarding the stability of most models over time and the notably poor psychometric properties associated with most cognitive learning style instruments (Coffield et al., 2004; Markham, 2004; Metallidou & Platsidou, 2008). This points to the critical importance of selecting or developing appropriate methods to assess cognitive learning styles as a component of future studies intended to establish if positive associations may exist between various models and analogical problem solving. Despite the difficulties involved, this particular avenue of research may be an especially significant one, as it could lead to enhanced understanding of ways in which to facilitate the practical development of transfer skills.

4.8. Expertise and familiarity

According to Zook (1991), “... a complex interaction between analogical similarity and prior knowledge may determine the ... outcome that is achieved through the mapping process” (p.58); and Holyoak (2012) notes that it is important to consider the role of previous experience in determining which approaches, schemas, or strategies individuals may bring to bear when faced with a novel problem. These propositions highlight the necessity of considering the extent to which both *expertise* (mastery of content and tasks in a particular domain or area) and *familiarity* (previous exposure to content and tasks in a particular domain or area) may play a role in analogical transfer (Antonietti & Gioletta, 1995; Barnett & Ceci, 2002; Lee, 1992).

It is widely presumed that increased familiarity with the domain in which the underlying structure is embedded augments analogical problem solving, particularly if the solver is able to draw on established schemas or other stored knowledge during the solution process (Billing, 2007; Corkill & Fager, 1995; Gick & Holyoak, 1983; Jonassen, 2000; Kokinov & Petrov, 2000). The empirical evidence that is available, however, does not provide unequivocal support for this supposition. For example, Corkill and Fager (1995) initially asked participants (undergraduate university students) to rank the extent to which they felt four common analogues of the convergence schema (the radiation problem itself, the fire chief, the general, and the lightbulb) were familiar. Fifty-one of eighty-two subjects ranked the general and fire chief analogues as more familiar than the lightbulb and radiation problems, possibly based on the scientific nature of the latter. This pattern regarding familiarity was duplicated in a validation study conducted with an additional seventy-seven participants. In their main study, Corkill and Fager (1995) then assessed whether various combinations of the familiar and unfamiliar analogues acting as source and target could provide conclusive evidence that familiarity enhanced analogical transfer. Specifically, they paired either a more familiar (the general) or a less familiar (the radiation problem) source with either a more familiar (the fire chief) or a less familiar (the lightbulb) target. Their results indicated that overall one hundred and five participants produced analogical solutions; fifty-six of these received the more familiar analogue (the fire chief) as a target and forty-nine of these received the less familiar analogue (the lightbulb) as a target. Of those who solved spontaneously, twenty-nine received the more familiar target and thirty-two received the less familiar target. These findings indicated that familiarity with the target did not significantly improve rates of either spontaneous or directed transfer. Corkill and Fager (1995) also observed an unexpected trend during a post-hoc evaluation of the quality of the summaries produced during the experiment; they noted that participants who had received a less familiar source tended to produce higher quality summaries (linked to schema quality). They thus proposed that less familiarity could potentially be beneficial in encouraging a greater degree of concentration and effort during encoding (Corkill & Fager, 1995).

Other studies exploring familiarity have focused on whether likely variations in level of domain knowledge would play a role in determining analogical solution rates. Keane (1985) found that rates of analogical problem solving of the radiation problem as a target between students studying mathematics and students studying psychology were not significantly different; Antonietti and Gioletta (1995) suggested that this may have been due to students from both disciplines considering themselves equally unfamiliar with the medical field. To address this, they conducted a comparison of rates of analogical transfer for the radiation problem and a technical isomorph (the artificial lake) between students registered for

humanities courses and students registered for biology or medicine at a university level. Their results indicated that medical students who had received at least a year of instruction within the discipline produced a significantly higher rate of transfer than humanities students who had also studied for at least a year in their chosen discipline. Although this did suggest that those who were more familiar with the target discipline were advantaged, Antonietti and Gioletta (1995) also noted that it was impossible to distinguish between the effects of familiarity and other potential differences between the groups such as instructional practice or type of teaching received.

On the basis of the evidence available, it is thus currently unclear as to whether increased familiarity with the relevant domain assists or hinders analogical transfer; and further research to clarify this contradiction is patently necessary. In contrast to this, understanding of the role played by expertise in expediting analogical problem solving is relatively well established. This is partly as a result of the extensive focus given to understanding distinctions in performance between novices and experts during problem solving for a wide typology of tasks and problems, including those of an analogical nature (cf. Bearman et al., 2002; Chi et al., 1981; Condell et al., 2010; Kahney, 1993; Novick & Holyoak, 1991; Thomas, 2008).

Problem solving expertise is typically domain-specific and develops through exposure to multiple examples of problems that share features allowing them to be classified within a given category or set. Through this repeated exposure, experts develop heavily enriched generalized structural representations (problem solving schemas) for that class of problem that allow them to identify, adapt, and solve other exemplars within the same category highly efficiently (Bassok, 2003; Gick, 1986; Holyoak, 1984; Lee, 1992; Novick & Holyoak, 1991; Thomas, 2008). Experts are thus more adept at recognising, encoding, and grouping problems on the basis of shared underlying structural correspondences; whereas novices tend to focus on superficial similarities or shared contextual features (Bearman et al., 2002; Chi et al., 1981; Ozkan & Dogan, 2012; Reeves & Weisberg, 1994; Thomas, 2008). Novices also typically produce less elaborate problem representations; whereas experts tend to incorporate additional relational, procedural, and implicit information that allows for a more nuanced application of the solution strategy (Chi et al., 1981; Gentner & Smith, 2013; Kahney, 1993; Thomas, 2008).

Thomas (2008) notes that experts “... are less likely to be distracted by object differences. As experts' mapping is guided by underlying structural features of problems, they are able to map correctly even when the contextual features of the problem are

considerably different' (p. 255). In contrast to novices, who tend to fixate on similarities in surface or contextual details, experts are thus more proficient in connecting problems on the basis of shared causal or logical relations that point directly to the common solution applicable to all problems of that particular type (Bassok, 2003; Gentner, 1989; Holyoak, 1984; Lee, 1992; Richland & McDonough, 2010; Zook, 1991). Experts are also better equipped to utilise structural similarity as the basis for retrieval when searching in long-term memory for relevant previously encountered problems; whereas novices tend to use shared surface or contextual features as retrieval cues and thus struggle to bridge the gap between superficially different exemplars from the same broader problem category (Blanchette, 2000; Chai et al., 2015; Gentner et al., 2003; Gick, 1986; Holyoak, 2012; Speicher & Kehrhahn, 2009; Thomas, 2008; Zook, 1991).

Expertise within a given domain is thus widely regarded as a facilitator of both analogical transfer between isomorphic problems and schema development and utilisation (Chai et al., 2015; Condell et al., 2010; Lee, 1992; Novick & Holyoak, 1991). This is supported by empirical evidence obtained from several studies. For example, Novick (1988) was able to show that those with mathematical expertise (represented by performance on the mathematical section of the SAT) were more likely to spontaneously transfer the correct solution procedure to remote analogues and were less likely to persist in using a distractor solution procedure; while novices were more vulnerable to negative transfer effects. In another study exploring differences in classroom-based problem representation between novice and expert teachers, Hogan (2005) found that expert teachers consistently relied on deep, structural features (foundational aspects of instruction, assessment, and curriculum planning) whereas novice teachers focused on surface features (narrative characteristics). Novick and Holyoak (1991) utilised both mathematical and verbal SAT scores as estimates of mathematical and verbal expertise; and then examined the extent to which these acted as predictors of transfer performance between isomorphic mathematical story problems. As expected, their results indicated that mathematical expertise was a significant predictor of analogical problem solving (although verbal expertise was not); they attributed this to superior representational, retrieval, and mapping skills as well as an enhanced understanding of the constituent elements of the requisite mathematical procedures and a consequent reduced processing load (Novick & Holyoak, 1991). It is also worth noting that although certain studies conducted in more naturalistic environments have identified a higher rate of utilisation of deep structural features by novices than suggested within the standard experimental literature (cf. Bearman et al., 2002; Blanchette & Dunbar, 2000; Gentner & Smith, 2013); this raises questions regarding the extent of the benefit afforded by expertise rather than undermining the general positive effect altogether.

4.9. Creativity

Creativity, the perception or production of something original, innovative, or previously not thought of, has been proposed as both a facilitator and a product of analogical reasoning and problem solving (Corkill & Fager, 1995; Green et al., 2012a; Kao, 2014; Kim & Horii, 2015; Mumford, Medeiros, & Partlow, 2012). Creative ability is thought to aid identification of the shared relational structure between two situations, particularly during cross-domain or far transfer where these may contain few obvious similarities (Chai et al., 2015; Day & Goldstone, 2012; Gentner & Colhoun, 2010; Holyoak, 2012; Thomas, 2008; Weinberger, Iyer, & Green, 2016; Zook, 1991). Creative thought is also a possible outcome of the analogical process in cases where gaps between seemingly unrelated or remote scenarios are bridged and unique or novel associations or perspectives revealed (Chai et al., 2015; Corkill & Fager, 1995; Kao, 2014; Kim & Horii, 2015; Klavir & Gorodetsky, 2011; Ozkan & Dogan, 2012).

As part of their larger study of individual differences in analogical problem solving, Corkill and Fager (1995) assessed creativity using the unusual uses section of the Torrance Test of Creative Thinking (Form B) in a sample of sixty-five final year high school students and one hundred and sixteen undergraduate university students. Their results indicated that creativity was not a significant predictor of overall spontaneous transfer between isomorphs of the convergence schema; however it was a significant predictor of overall directed transfer (whether an analogical solution was produced after a hint to utilise the source was given). Creativity scores were also a significant predictor of spontaneous transfer when subjects were given a less familiar source (the radiation problem) and a more familiar target (the fire chief). Corkill and Fager (1995) noted that some of the relationships between creativity and analogical problem solving may have been masked in their study due to confounding (particularly the overlap between creativity scores and scores on the verbal analogies test). They also proposed that the relationships that were identified could potentially be due to those with higher levels of creativity being more skilled in recognising and mapping structural correspondences between the analogues.

Cushen (2012) explored the relationship between performance on a measure of divergent thinking (the Remote Associates Task) and analogical problem solving (assessed using rate of transfer between the lightbulb analogue as a source and the radiation problem as a target) in a sample of one hundred and twenty undergraduates. His findings indicated that divergent thinking was significantly associated with both spontaneous and directed

transfer (correlations of $r = 0.36$ and $r = 0.35$ respectively), as well as with perceived helpfulness of the source (a correlation of $r = 0.27$). Divergent thinking has also been shown to be a significant predictor of spontaneous transfer performance (Cushen & Wiley, 2018). In a different vein, Klavir and Gorodetsky (2011) asked their participants (gifted and regular eighth and ninth grade students) to construct new structurally isomorphic but superficially variant problems after exposure to source problems containing the original solution strategies (one was mathematical, one mathematical-insight, and one verbal-insight). Their results indicated that those students who were more intellectually gifted were more likely to produce new problems that were structurally aligned with the original exemplars; these students also showed higher levels of creativity.

Although additional confirmation, particularly regarding the resiliency of the effect across different contextual scenarios, is required; there is a fairly consistent pattern evident in the studies that are available. Taken together, these support the proposition that creative ability facilitates analogical problem solving.

4.10. Affective and conative factors

According to Jonassen (2000), “...*affective elements, such as attitudes and beliefs about the problems, problem domain, and the learner's abilities to solve the problem, significantly affect a problem solver's abilities... conative (motivational and volitional) elements, such as engaging intentionally, exerting effort, persisting on task, and making choices, also affect the effort that learners will make...*” (p.71). Day and Goldstone (2012) argue that the nature of the goals posed by an individual during problem solving is likely to substantively influence both their degree of engagement with the task and their ultimate success. These goals are intrinsically linked to motivation, which, in turn, is at least partially determined by level of interest, perceptions of capability and likely success, and emotional state (Jonassen, 2000; Mayer, 1998).

Despite its potential relevance, to date there appear to be very few studies that have explored the relationship between analogical problem solving and *affect*, an individual's emotional response to a situation, feelings, or mood (Isen, 2001; Reber, 1985). Two notable exceptions are studies by Jausovec (1989) and Izsof Jurasova et al. (2014). Jausovec (1989) conducted three experiments in which he presented participants with a source problem and then primed them to experience either positive, neutral, or negative affect through watching films before solving the target problem. His results indicated that positive affect decreased rates of analogical transfer between well-defined problems but enhanced

analogical problem solving for ill-defined problems. Izsof Jurasova et al. (2014) conducted a similar experiment in which they induced either a positive or a negative emotional state in their participants through watching film clips before asking them to solve target problems. Their findings suggested that a negative emotional state (sadness) facilitated analogical problem solving whereas a positive emotional state (amusement) facilitated non-analogical solving. Given that these results directly contradict one another, as well as the extremely small pool of studies available, it is highly evident that additional research is required before any form of conclusion regarding the potential relationship can be made.

There is equally little research available regarding the potential links between analogical problem solving and other affective and conative factors. In their study of naturalistic conversation occurring between scientists working on the Mars Rover Mission, Chan et al. (2012) did find that the use of analogies was an effective method for reducing expressed uncertainty, which would presumably result in a concomitant reduction of experienced emotional tension. There is also a fair degree of evidence available that suggests that both mapping and analogical reasoning are impaired if levels of anxiety or stress are increased even slightly (cf. Holyoak, 2012; Vendetti et al., 2012), although to date there do not appear to be any similar studies available that have examined analogical problem solving directly. In another study focusing on motivation, Whitmire (2001) explored whether either trait curiosity or offering a material reward affected analogical insight or analytical problem solving. His findings suggested that the offer of an external reward had no effect on solution rates; however higher levels of *diversive trait curiosity*, exploratory behaviour motivated by feelings of boredom or a desire for excitement, were linked to better performance on the analogical insight problems (Litman & Spielberger, 2003; Whitmire, 2001).

Although these studies provide highly preliminary indications that the connections between analogical problem solving and various affective and conative factors are likely to parallel those identified for problem solving more broadly, the empirical evidence that is currently available is extremely inadequate and it is clear that considerable additional work is required. This is likely to continue to be hampered by the difficulty of meaningfully assessing these types of factors during lab-based experiments, as they are highly situationally dependent and thus particularly vulnerable to reactivity and observer effects (Rosenthal & Rosnow, 2008; Stangor, 2015).

4.11. Demographic factors

One of the few demographic factors that has received a relatively high degree of attention within the existing literature is *age*, specifically as regards the development of the ability to work with and manipulate analogical relations (Abdellatif et al., 2008; Gentner & Smith, 2013; Goswami, 1991). Various researchers (cf. for example, Chen, Sanchez, & Campbell, 1997; Chen & Siegler, 2013; Gentner & Toupin, 1986; Goswami & Brown, 1990; Holyoak, Junn, & Billman, 1984; Tunteler & Resing, 2002) have demonstrated that even toddlers between a year and three years old are able to reason and solve problems analogically provided that the task content and requirements are age-appropriate. However, as is the case with novices or those who lack expertise, younger children tend to be strongly cognisant of and easily distracted by surface similarity, lack highly developed and organised knowledge structures from which to draw stored information, and struggle to map effectively (Abdellatif et al., 2008; Gentner & Toupin, 1986; Holyoak, 2012; Thomas, 2008; Zook, 1991). As children grow older, their ability to identify and focus on structural similarity and draw relational inferences develops proportionately, a phenomenon termed the *relational shift* (Bassok, 2003; Gentner & Smith, 2013; Holyoak, 2012; Zook, 1991). This may occur as a result of enhanced capacities for processing and manipulating abstract information, increased exposure to and internalisation of experiential and semantic knowledge, gains in inhibitory control, or combinations of these and other maturational changes (Gentner & Smith, 2013; Holyoak, 2012; Richland et al., 2010; Richland, Morrison, & Holyoak, 2004; Zook, 1991).

In contrast to the interest in development, there appears to be little empirical research that has attempted to validate or challenge assumptions of relative stability in analogical problem solving capacity during adolescence and early to mid-adulthood. Corkill and Fager (1995) did explore whether there were age-related distinctions in analogical problem solving between samples of high school and first-year university students and found no significant differences; however they acknowledge that this may have been an artefact of the restricted age range. This appears to be a common barrier as a majority of published studies exploring analogical problem solving have utilised university samples (possibly due to pragmatic constraints). There also appear to be very few studies that have explored age-related shifts in analogical problem solving with older adult populations, although there is some research that has examined age-related differences in other forms of analogical reasoning (cf. Bugaiska & Thibaut, 2015; Clark, Gardner, Brown, & Howell, 1990; Salthouse, 1987; Viskontas et al., 2004). In a recent study, Li, Zhuang, and Peng (2018) found that younger adults (average age twenty-two) appeared to be less reliant on surface similarity than older

adults (average age sixty-nine), although both groups performed best when increased surface and structural similarity were present.

Similarly, although there is a large body of research available regarding gender-based performance differences for other forms of analogical reasoning and cognitive tasks generally (cf. for example, Furnham, 2001; Halpern, 1997; Halpern, Beninger, & Straight, 2011; Irwing & Lynn, 2005; Johnson & Bouchard, 2007; Neisser et al., 1996), there appears to be almost no work available that directly explores distinctions in analogical problem solving on the basis of *gender*. One exception to this is a series of studies by Antonietti and Gioletta (1995), who found that in four of their five experiments, males outperformed females when given the radiation problem as a target and a source analogue about an artificial lake (although the relationship between gender and analogical problem solving was only significant in one experiment). In their fifth experiment, which was the only one in which females outperformed males (although not significantly), they noted that interaction effects between gender and familiarity may have affected the results as the medical sample had a higher proportion of females than the humanities sample. Antonietti and Gioletta (1995) also proposed that stereotypical beliefs regarding expected problem solving success and traditional masculine/ feminine content may have played a role in determining the different rates of transfer observed between the genders. Both of these possibilities, as well as the extent to which differences in analogical problem-solving on the basis of gender exist in the first instance, represent important directions for future research, particularly in light of the current lack of information.

Several studies have been conducted exploring the effect of *language* on analogical problem solving and transfer. Bernardo (1998) conducted three experiments in which he examined language-compatibility effects among bilingual participants (English-Filipino). His results indicated that presentation of the source and target in the same language facilitated retrieval for superficially similar analogues (but not for superficially dissimilar ones); and also confirmed that language format was not directly related to mapping or application of structural features. These findings are aligned with those of Francis (1999), who utilised samples of English-Spanish bilinguals to explore transfer between the radiation problem and two source analogues (the general and the lightbulb) presented in either Spanish or English. Her results demonstrated that language consistency between the source and target did not affect either retrieval or mapping; supporting the hypothesis that these processes might be language-general in nature. Her results also showed that transfer rates were lower for bilingual participants who received a target problem presented in their weaker or non-dominant language; this finding was essentially the same as that of Wakebe et al. (2015)

who found that transfer difficulty increased if the target was presented in a foreign language. Francis (1999) proposed that this may have been due to different processing requirements or the interaction between language and culture, both in terms of the propensity to utilise a particular language and in terms of the context or milieu created through use of that language.

This general pattern of results was confirmed by Fukumine and Kennison (2016), who found that analogical transfer in a sample of English-Spanish bilinguals was not related to language proficiency in the language the source was presented in, but was linked to the language the target problem was presented in. Specifically, significantly higher rates of spontaneous analogical transfer were observed for participants with higher rates of fluency in the language of the target problem. Fukumine and Kennison (2016) argue that this corroborates conclusions from previous work suggesting that source comprehension and encoding are essentially language-neutral (cf. Bernardo, 1998; Cushen, 2012; Francis, 1999). It is, however, important to note that their findings also suggest that the later stages of analogical problem solving, particularly adaptation, may be more difficult to enact successfully if the target problem is presented in a language the solver is less fluent in (cf. Francis, 1999; Fukumine & Kennison, 2016; Wakebe et al., 2015).

Despite the findings above, there appear to be few studies that have directly explored the effect of *home language* on analogical transfer performance. One exception to this is Cushen (2012), who identified no differences in rates of spontaneous or directed transfer for the radiation problem and the lightbulb source analogue presented in English between English monolingual, early bilingual, or late bilingual participants. Although this suggests that home language may not play a role in determining analogical problem solving success, additional empirical work is needed to support or refute this proposition.

In addition to language, any number of other features such as nationality, ethnicity, religious orientation, socioeconomic status, environmental proximity, and even philosophical choice can be used to delineate culture (Buchtel & Norenzayan, 2008; Güss & Wiley, 2007; Matsumoto & Juang, 2013). This is because it can be represented by any characteristic that allows for the development of “...*implicit and explicit shared knowledge that is transmitted from generation to generation*” (Güss & Wiley, 2007, p.4) and “...*provides a common lens for perceiving and organising (structuring) reality*” (Veroff & Goldberger, 1995, p.1). Thus *culture*, as a broad term used to indicate shared patterns of practice and underlying value systems, is another potential source of individual differences worth considering in relation to problem solving.

It has been suggested that cultural distinctions in problem solving may occur as a result of differences in knowledge, interpretation, patterns of attention, strategy choice, motivational orientation, and injunctive norms stemming from divergent socialisation practices and life experiences (Buchtel & Norenzayan, 2008; Chen et al., 2004; Güss & Wiley, 2007; Richland et al., 2010). Richland et al. (2010) note that “...*knowledge of cultural content may impact prerequisite knowledge of relations and, consequently, influence analogical reasoning on problem-solving tasks that rely on that cultural knowledge... normative patterns for drawing relational inferences during problem solving can vary across cultures when content knowledge is comparable*” (p. 147). In their own study, Richland et al. (2010) conducted a cross-cultural comparison of performance on a scene analogy task between pre-school age children from the United States and Hong Kong. Their results indicated that the Chinese children were more efficient in coping with relational complexity, which they attributed to “...*greater experience with socialized relational inputs*” (p. 152) derived from interactions with caregivers and at school. Chen et al. (2004) examined performance by Chinese and American participants on six insight problems, two of which were isomorphs of a common Chinese folktale (the elephant) and a well-known Western fairy tale (Hansel and Gretel). Their results showed no differences in solution rates between the different cultural samples for the control problems, however American participants were more likely to solve the Hansel and Gretel target analogue successfully and Chinese participants were more likely to solve the elephant target analogue successfully. Chen et al. (2004) concluded that this provided “...*clear and compelling evidence that participants are capable of drawing on culturally specific experience in solving analogous problems*” (p. 419).

Despite the clear relevance of other sources of cultural variation, particularly socioeconomic status and educational/ schooling experience, to date nationality and language appear to be the only parameters that have been explored directly in terms of their relationship to analogical problem solving in adults. As with gender, this highlights gaps in existing theoretical conceptualisations of which demographic factors influence successful analogical problem solving and to what extent; this, in turn, underscores the need for further research.

4.12. Interactions

In light of the lack of evidence available regarding the potential associations between analogical problem solving and the vast majority of individual difference factors, it is unsurprising that there are also relatively few studies that have examined interactions

between various individual difference factors, or between individual and process-based factors, in attempts to explore how these might jointly contribute to successful analogical problem solving. One exception to this is work by Corkill and Fager (1995), whose findings suggest that the relationships between creativity, verbal analogical reasoning, and deductive reasoning may explain their shared facilitative effects on successful analogical transfer. Similarly, Cushen and Wiley (2018) argue that the unique contributions made by attentional control and the ability to make remote associations in predicting spontaneous transfer in their study support the proposition that both focussed and diffuse attentional states are important components of analogical problem solving. In other studies of a similar type, Ma (2002) found that participants of higher intelligence who were also prone to utilising an explorer cognitive style produced more analogical solutions; while Hsu and Wedman (1994) established that participants who were field independent and who were then provided with multiple practice opportunities and a principle summary outperformed any other group in their study. Novick and Holyoak (1991) identified provision of multiple analogues, schema quality, mathematical expertise, and knowledge of numerical correspondences as key joint predictors of analogical transfer across several mathematically-based isomorphic problems; they also noted that neither verbal dexterity nor general analogical reasoning skill played a significant predictive role. In another study exploring the joint impact of problem-based and individually-based factors, Kubricht et al. (2015; 2017) established that the effect of using animation during presentation of the source on successful analogical problem solving was moderated by the participant's level of fluid intelligence (animation enhanced transfer to a greater extent for those with lower fluid intelligence scores).

Although these findings yield a number of interesting possibilities in terms of the interplay between various predictive factors, their dissimilarity and lack of coherence makes it difficult to determine any consistent patterns. There is thus a critical need for additional information regarding the combined interactive effects of a host of potentially relevant individual difference and problem-based factors; as this information both constitutes and contributes to the required empirical base from which comprehensive and elaborate theoretical models of analogical problem solving can be formulated.

4.13. Conclusion

This chapter has presented a number of critical findings regarding the links between a range of individual difference factors and analogical problem solving established in the field to date. The current study seeks to extend these understandings, as outlined in the sections that follow.

4.14. The current study: Broad conceptualisation

Analogical problem solving, particularly across different domains, has been shown to support knowledge integration and expansion, creativity and innovation, learning, skills transfer, and strategic practice (Antonietti, 1996; Gentner & Smith, 2012; 2013; Gick & Holyoak, 1980; Holyoak, 2012; Kaminski et al., 2013; Mason & Tornatora, 2016; Richland & McDonough, 2010; Thomas, 2008; Zook, 1991). As such, the ability to implement analogy as a heuristic strategy is a critical skill that underpins much of educational practice and occupational functioning; and its development or enhancement is a highly desirable outcome. This provides a logical explanation for the imbalance of focus prevalent in the available literature and highlighted by the review above. Specifically, much of the empirical evidence and theoretical emphasis to date has skewed towards exploring or confirming the nature of the associations between analogical problem solving and a host of process-based or context-based factors, particularly those thought to facilitate analogical transfer and schema development. Although this is a vital pursuit, it appears to have also promoted a certain degree of neglect as regards exploration of the role played by factors located within the problem solver as an individual. This knowledge, although less tangible and often more sensitive, is equally essential for the development of complete and enriched theoretical models of analogical problem solving that are able to support its practical implementation and augmentation.

Thus, and at the broadest level, the core underlying motivation for the current study was to further develop an understanding of the nature of the relationships between analogical problem solving and certain individual difference factors; with a view to providing a small yet original contribution able to inform and enhance existing theory. To this end, and through careful consideration of the state of knowledge embodied in the review above, it was possible to identify several emergent themes and gaps that constituted a basis for the parameters of the current research, including opportunities for novelty. A more detailed explanation of this as well as a list of the final research questions posed follows below.

4.14.1. Selection of core individual difference factors.

As is evident from the review above, findings from studies exploring the roles played by various individual difference factors in determining analogical problem solving skill are sporadic, often incongruent, and occasionally contradictory; it can also be difficult to

reconcile results given the lack of consistent theoretical and methodological focus across the available literature. There is thus a strong need for additional research that validates, confirms, improves upon, or expands existing evidence as regards nearly all of the multiple individually-located factors identified as potentially affecting analogical problem solving. From a practical perspective, however, it is not possible to focus on the entire range of variables requiring further investigation within the confines of a single study; thus an attempt was made to select those individual difference factors that were deemed most likely to promote an expansion of existing theory and the development of novel understandings.

Of those factors that have been explored, arguably the most puzzling and ambiguous findings are those that centre on the relationship between the skilled use of analogy as a problem solving heuristic and other forms of analogical reasoning (which are also representative of general intelligence). In terms of pure theorization, there is a strong tendency for these to be seen as slightly variant superficial manifestations of the same shared underlying ability (Barnett & Ceci, 2002; Holyoak, 1984). They are generally regarded as drawing on the same pool of core component skills; and evidence related to either phenomenon is often transposed as applicable to the other. As such, they appear to be widely perceived and treated as interchangeable across the available literature (cf. Abdellatif et al., 2008; Embretson & Schneider, 1989; Gentner & Smith, 2012; Goswami, 1991; Holyoak, 1984; 2012; Kahney, 1993; Morrison, 2004; Zook, 1991). This supposition is in line with standard reductionist assumptions regarding the generalisability of data obtained under simplified and controlled conditions to more complex and real-world tasks (as the solution of more elaborate isomorphic problem tasks is often interpreted as a natural extension of solving traditional four-term proportional analogy problems) (Blanchette, 2000; Ericsson & Hastie, 1994; Gick & Holyoak, 1983; Lee, 1992; Thomas, 2008; Trench & Minervino, 2015; Zook, 1991). However, although the hypothetical parameters appear clear, the empirical evidence that is available to date regarding the association between analogical problem solving and analogical reasoning appears to (at least partially) conflict with these. More specifically, several of the studies that have been conducted have identified no significant relationship between the two constructs at an empirical level (cf. Antonietti & Gioletta, 1995; Jausovec, 1993; Novick & Holyoak, 1991); others suggest a degree of association but of a strength not entirely aligned with the close relationship implied in the literature and in some cases only under specific conditions (cf. Corkill & Fager, 1995; Klein, 1994; Kubricht et al., 2015; 2017; Ma, 2002; Vendetti et al., 2014b). These findings, in turn, have elicited suggestions that at the very least the presumed empirical indicators of these constructs may diverge in terms of the demands placed on the solver, and may thus tap (at least partially)

distinct sets of underlying capabilities (Goswami, 1991; Holyoak, 1984; Kahnem, 1993; Novick & Holyoak, 1991; Thomas, 2008).

This schism between the widely held conceptualization of and empirical data relevant to the concepts in question has potentially profound implications for theoretical understanding of the notion of analogical problem solving (Holyoak, 1984). If a consistent pattern suggesting there is no association (or even a highly limited one) between analogical problem solving and analogical reasoning is established empirically, this raises fundamental questions regarding the relevance of many of the notions held standard when describing the analogical problem solving (and transfer) process. This, in turn, may alter perceptions regarding ideal practice and shift conceptions regarding implementation. In contrast, should a moderate or strong relationship between the two be identified, this would lend critical support to prevailing principles and uphold much of the existing literature and consequent suggested application.

It is also vital to note that many of the studies carried out thus far exploring the relationship between analogical reasoning and analogical problem solving are open to methodologically-based critique or concerns. These include concerns regarding sample size, particularly given typical rates of spontaneous transfer which usually fall between twenty and forty percent of a given sample, as well as the tendency towards reliance on single measures of relevant constructs. Arguably the most consistent concerns, however, are those regarding the operationalisation of analogical reasoning skill (and intelligence). For example, both Novick and Holyoak (1991) and Corkill and Fager (1995) utilised the verbal reasoning (verbal analogies) subtest of the Differential Aptitude Test (DAT), which has a relatively unique response format requiring the solver to provide two of the four terms for each proportional analogy. It is therefore possible that issues of reliability, validity, or bias peculiar to this particular subscale may have affected the results obtained (Murphy & Davidshofer, 2005; Salkind, 2006). Antonietti and Gioletta (1995) utilised the Raven's Standard Progressive Matrices (RSPM) as a measure of non-verbal analogical reasoning; however the RSPM have been shown to exhibit range restriction and ceiling effects in university samples (cf. Jensen, Saccuzzo, & Larsen, 1988; Raven, 2000; Rushton, Skuy, & Fridjhon, 2003) which may have limited variability in the categorical divisions created for their statistical analysis. Although Kubricht et al. (2015; 2017) and Vendetti et al. (2014b) utilised versions of the Raven's Advanced Progressive Matrices, which are more appropriate for university samples, in both studies shortened, adapted versions of the original scale were given to participants which may or may not have yielded equivalent estimates of performance. From a different angle, both Jausovec (1993) and Klein (1994) categorized

participants as gifted or of average intelligence based on various indicators of academic performance, which, while related to intelligence, is not typically considered the strongest correlate thereof (Neisser et al., 1996).

There is thus a strong need for further, more formalized research that not only provides a more intensive and rigorous exploration of the nature of the association between analogical problem solving skill and analogical reasoning ability but also attempts to address the various methodological concerns raised when considering previous studies. To this end, a primary aim of the current project was to assess both verbal and non-verbal analogical reasoning within the same sample group (using improved instrumentation) and to establish to what extent these were predictive of skilled transfer performance. Given the potential significance of this particular relationship, this focus was clearly merited; however it is worth noting that as a consequence of this aim, both practical concerns (time, access to suitable instrumentation, and the amount of testing required) and technical issues (potential confounding and statistical multicollinearity) precluded the inclusion of certain other important factors strongly indicated in the literature, particularly working memory and levels of innate creativity.

Another group of factors that have been identified within the literature as associated with analogical problem solving skill are those related to metacognitive and epistemological functioning, particularly declarative knowledge, familiarity and expertise, and field in/dependence (Antonietti & Gioletta, 1995; Antonietti et al., 2000; Bearman et al., 2002; Billing, 2007; Corkill & Fager, 1995; Jonassen, 2000; Klein, 1994; Metallidou & Platsidou, 2008; Novick & Holyoak, 1991; Thomas, 2008; Wedman et al., 1999). A closer examination of the patterns of findings in these areas, however, promotes recognition of an interesting and potentially vital omission. Specifically, there appears to be a nearly complete lack of evidence regarding the extent to which successful implementation of an analogical problem solving approach may be guided or influenced by the overt choice of heuristic strategy used to initiate the solution process (no direct evidence regarding this factor could be sourced despite extensive searching).

There are numerous heuristic and algorithmic strategies prevalent throughout the problem solving literature (cf. Chen & Siegler, 2013; Condell et al., 2010; Gick, 1986; Holyoak, 1995; Koichu et al., 2003; Ohlsson, 2012; Wang & Chiew, 2010). Almost all of these can be encapsulated within the synthesised framework developed by Antonietti et al. (2000); which divides the various strategies into five broad clusters, namely: free production, combining, step-by-step analysis, visualisation, and analogy. According to empirical

research, these strategy sets differ in terms of their perceived frequency of use, efficacy, and ease of implementation; with analogy typically reported as the most commonly applied and one of the most effective and easiest to utilise (Antonietti et al., 2000; Güss & Wiley, 2007). Despite this, solution by analogy is only one of several possible heuristic methods or approaches available when faced with a novel problem; and individuals appear to develop, master, and apply these strategies differentially based on age, learning context, background experience, and field of application (Antonietti et al., 2000; Gick, 1986; Kahney, 1993; Taggart & Valenzi, 1990; Treffinger & Selby, 2004; Treffinger, Selby, & Isaksen, 2008). Antonietti and Gioietta (1995) therefore argue that “... [because] retrieval and application of the source are one of the possible strategies that individuals can employ to solve the target, preference toward a particular kind of reasoning, rather than ability, may be a relevant variable...” (p. 613). This proposition is consistent with the notion of habitual problem solving style – “...consistent individual differences in the ways people prefer to plan and carry out generating and focusing activities...” (Treffinger et al., 2008, p. 393), leading to the development of solutions to novel problems (Hamlen, 2018; Treffinger et al., 2008). Various dimensions of problem solving style have been identified in the literature, including processing, decision-making, and change preferences (cf. Selby, Treffinger, Isaksen, & Lauer, 2004; Taggart & Valenzi, 1990); although minimally explored to date, it seems eminently sensible to propose that conscious heuristic strategy preference may constitute another facet of problem solving style worthy of consideration (cf. Antonietti et al., 2000; Martin, 1998).

Of the various strategy sets, a preference for solving through the application of analogy would appear to be the most likely to promote skilled analogical transfer; as this may either initiate or facilitate retrieval, correspondence identification/ mapping, and adaptation through encouraging active searching for suitable previously encoded instances or resources that would apply to the current situation (Antonietti et al., 2000; Gentner & Smith, 2012; Gick & Holyoak, 1980; Güss & Wiley, 2007; Holyoak, 2012; Yanowitz, 2001). This potential link is so powerful and intuitive that within certain sections of the literature there even appears to be a presumption that the choice of analogy as a preferred overt heuristic strategy would be a necessary pre-condition of successful analogical transfer. To date, however, there appears to be no empirical evidence available that either supports or contradicts this supposition. Similarly, the extent to which openly generating multiple solution options (free production), forming novel integrations or interpretations of existing patterns (combining), creating and altering perceptions of essential problem features (visualisation), and methodically working through a hierarchy of actions (step-by-step) might contribute to expediting analogical problem solving remains unknown, although each could potentially

enhance various components within the broader analogical process (Antonietti et al., 2000; Güss & Wiley, 2007; Metallidou & Platsidou, 2008).

Evidence of the potential associations between conscious heuristic strategy preference and analogical problem solving is potentially critical to obtain as it could contribute substantively to enhancing understanding of ways in which to promote and expedite identification of isomorphic structures shared between problems from different domains, thus enriching opportunities for schema formation, creativity, innovation, and long-term exemplar-based learning (Gentner & Smith, 2012; 2013; Gick & Holyoak, 1983; Holyoak, 2012; Thomas, 2008). Improved understanding of the extent to which the analogical problem solving process may be influenced by conscious heuristic choice may also contribute to more developed conceptualisations of the conditions under which intentional and implicit analogical transfer may occur (cf. Anolli et al., 2001; Chen et al., 2004; Day & Goldstone, 2012; Gentner & Smith, 2012; 2013; Holyoak, 2012). Given this, and with a view to extending existing theory regarding the effective deployment of previous knowledge during the analogical problem solving process, another primary aim of the current research project was to explore the nature of the associations between analogical transfer performance and conscious heuristic strategy preference (including the development of a suitable instrument to assess the latter construct).

4.14.2. Context and selection of secondary individual difference factors.

South Africa is generally recognised as one of the most diverse societies in the world; in addition to eleven recognised national languages, multiple other dialects are spoken, and there is a high degree of variation as regards race, religion, cultural orientation, ethnic background, and lifestyle (Beck, 2014; Encyclopaedia Britannica Online, 2018; South Africa.info, 2015). As a result of systematic discrimination and deprivation imposed on large sections of the population on the basis of race during the colonial and Apartheid eras, South Africa also remains one of the most economically and educationally imbalanced societies in the world (Spaull, 2013a; van der Berg et al., 2011). It is estimated that at least a quarter of the population live under conditions of relatively extreme poverty and lack access to adequate resources, including housing, food, healthcare, transport, and sanitation. There are also substantive variations in the quality of educational infrastructure and resources available within different schools at all educational levels, often on the basis of location (including urban versus rural) and school governance (including government-run or private) (Beck, 2014; Encyclopaedia Britannica Online, 2018; Marais, 2010; South Africa.info, 2015;

Spaull, 2013a; van der Berg et al., 2011; Yamauchi, 2011). As a consequence of these circumstances, the South African context is widely seen as unique; this, in turn, has profound implications regarding the extent to which theory developed in international populations and environments can or should be applied at a local level.

Whilst surveying the available literature, one of the most obvious omissions that became evident was the seemingly complete absence of research exploring analogical problem solving within South Africa (despite extensive searching no studies that examined rates of transfer between classic problem isomorphs in samples drawn from the South African population could be sourced (please refer to Table A.1 in Appendix A for a list of databases searched)). This was both surprising and concerning, particularly as evidence suggests that there are variations in problem interpretation, strategy choice, and capacity for coping with complex relational reasoning that stem from divergent cultural experience and practice (cf. Buchtel & Norenzayan, 2008; Chen et al., 2004; Güss & Wiley, 2007; Richland et al., 2010). Exposure to culturally-embedded knowledge, conventions, and traditions may also influence the formation and accumulation of stored information that can later be drawn on during representation and retrieval (Chen et al., 2004; Richland et al., 2010). Given this, as well as the incontrovertible importance and likely prevalence of analogy as both a problem solving heuristic and key learning mechanism in occupational and educational settings, there is a strong need for empirical research focusing on analogical problem solving in the South African context. This is particularly vital as both current theory and implementation rely on evidence drawn from international contexts; however the extent to which these findings are consistent and applicable within the unique South African milieu remains an open question. In order to contribute towards the compilation of data that could be utilised for cross-cultural comparison, one of the secondary aims of the current study was thus to explore rates of analogical transfer within a sample of South African university students (among other reasons, this particular population was selected in order to align with international work, which has almost universally focused on this grouping).

In addition, it is important to recognise that locating research within the South African context offers a unique opportunity for exploring the nature of the associations between analogical problem solving and various demographic variables, particularly those linked to cultural, economic, and linguistic diversity. This is especially important as to date there appear to be very few studies that have examined variations in analogical problem solving performance on the basis of gender (cf. Antonietti & Gioletta, 1995) or home language (cf. Bernardo, 1998; Cushen, 2012; Francis, 1999; Fukumine & Kennison, 2016; Wakebe et al., 2015); and none that have done so on the basis of socioeconomic status or type of

schooling. Additional research could thus not only assist in developing theory directly appropriate to South Africa (including enhancing understandings of the impact of diversity), but could also contribute towards increased comprehension of the roles played by these factors universally. A secondary aim of the current study was thus to explore whether rates of analogical transfer differed on the basis of gender, home language, socioeconomic status, or type of schooling.

4.14.3. Expanding the notion of analogical transfer.

As is evident from the review above, a large portion of the previous work conducted on analogical problem solving has followed a similar basic experimental procedure designed to ensure that participants have a degree of controlled exposure to at least one relevant source analogue. Typically this source material is presented to participants under the guise of completing a separate task, followed at a later point by presentation of the relevant target problem (allowing for intervening tasks or time lapses to occur as deemed desirable) (cf. Anolli et al., 2001; Antonietti, 1996; Barnett & Ceci, 2002; Bassok, 2003; Catrambone et al., 2006; Gick & Holyoak, 1980; 1983; Holyoak, 2012). One of the most useful features of this method has been the capacity to explore both spontaneous and directed (prompted) rates of analogical transfer between the source and target analogues, through manipulation of provision of a hint (Anolli et al., 2001; Corkill & Fager, 1995; Cushen, 2012; Gick & Holyoak, 1983; Kubricht et al., 2017; Richland & McDonough, 2010). The method can also be regarded as useful in classic quantitative design terms, as it promotes exploration of causal relationships through allowing for manipulation of the variables in question as well as measures to rule out extraneous effects (thereby permitting temporal precedence, covariation, and non-spuriousness criteria to be addressed to a relatively high degree if implemented appropriately) (Davis & Brenner, 2006; Rosenthal & Rosnow, 2008; Salkind, 2006; Stangor, 2015). From a purely practical perspective, the method is also one that allows for quantification and direct observation of a relatively intangible phenomenon (Gick & Holyoak, 1980).

Despite these advantages, and in line with common criticisms raised regarding quantitative methodology in general (cf. Babbie & Mouton, 2001; Stangor, 2015), there is a degree of apprehension that the level of control inherent in the approach may limit generalisability and alter the nature of the phenomenon under observation (cf. Bearman et al., 2002; Blanchette, 2000; Day & Goldstone, 2012; Nokes, 2009). Specific concerns raised have included limited opportunities for exposure to the relevant source material, the

tendency to present the two tasks in relatively close proximity both temporally and in terms of context, and, perhaps most importantly, the restricted scope of what is deemed to constitute transfer (Anolli et al., 2001; Catrambone & Holyoak, 1989; Chen et al., 2004; Lobato, 2006; Nokes, 2009; Novick & Holyoak, 1991; Reeves & Weisberg, 1994). Linked to this last point, critics argue that the assessment of transfer under experimental conditions is typically limited to establishing whether a specific shared isomorphic solution structure is identified and adapted by the participant; this precludes the identification of alternate shared correspondences that could favour different solution strategies and thus prioritises the interpretation of the experimenter (Day & Goldstone, 2012; Lave, 1988; Lobato, 2006; Nokes, 2009). It has also been contended that this approach relies on internalisation of a given source and thus disregards previously acquired knowledge and experience that would inevitably guide analogical problem solving in real-world circumstances (Antonietti, 1996; Day & Goldstone, 2012; Holyoak, 2012; Lave, 1988; Lee, 1992; Novick & Holyoak, 1991; Trench & Minervino, 2015).

In an attempt to address certain of these criticisms whilst still adhering to the core principles underpinning the traditional investigative approach, a relatively novel method of exploring transfer was developed and implemented in the current study. Specifically, in addition to completing a task where a relevant source was provided and assessed as regards application of the embedded principle (the convergence schema) to a later target problem (in line with standard methodology), participants were also given two potentially isomorphic problems but were not provided with a solution for either one. In line with the process adopted by Gick and Holyoak (1980) in their third experiment, participants were required to solve both problems and were then assessed as regards transfer of the solution they developed for one of these to the other. In contrast to Gick and Holyoak (1980), however, participants were not provided with any hint regarding a potential link between the two problems; and the order in which the problems were required to be solved (and thus which problem functioned as a potential source and which as a potential target) was not strictly controlled. Furthermore, although a possible shared solution strategy was identified from previous work, no presumption was made regarding which solutions would be deemed to constitute an analogical response prior to analysis of the data; and the extent to which the given solutions rested on the identification of mapped shared correspondences was appraised retrospectively.

It is important to note that a high degree of inference was required during this evaluation process; and the lack of control made it difficult to establish to what extent analogical overlap between the proposed solutions was intentional or overtly recognised by

the solver. Nevertheless, it can be argued that these features are also archetypal of at least some forms of analogical problem solving as they occur in real-world environments (cf. Holyoak, 2012; Trench & Minervino, 2015), where participants are able to draw on a wide range of potentially relevant exemplars and schemas stored in long-term memory in an unrestricted manner and may not always be overtly aware of doing so. The method also acknowledges the possibility of differing representational structures as applicable to the same overt stimulus problems; these, in turn, may support variations in identified shared correspondences leading to alternate yet still analogous solution strategies (thus the interpretation of the researcher as expert is not unduly privileged). Furthermore, this approach may also capture more implicit forms of transfer where analogical recognition does not necessarily occur within the ambit of conscious thought but still informs behavioural outcomes (cf. Chen et al., 2004; Day & Goldstone, 2012; Gentner & Smith, 2012; 2013; Holyoak, 2012).

On this basis, a third aim of the current study was to establish to what extent analogical transfer occurred under more open conditions, whether and to what extent this was associated with more classic assessments of transfer occurrence (specifically rates of directed transfer), and whether and how this related to the other key individual difference variables focused on within the study. This was considered as having the potential to be especially valuable as regards furthering theoretical understandings of the use of analogy as a heuristic; to date there appear to be no published studies that have explored rates of open transfer in this manner, or both directed and open transfer within the same group of participants. In addition to addressing many of the concerns raised regarding ecological validity, the notion of open transfer has the potential to substantively augment the range of potential suppositions available regarding analogical problem solving as a tangible phenomenon. Given that it draws on findings regarding the use of analogy in everyday circumstances (cf. Bearman et al., 2002; Blanchette, 2000; Day & Goldstone, 2012; Holyoak, 2012) and could yield results more relevant to direct application and practice within naturalistic settings, it could represent an important direction for extending existing conceptualisations of analogical problem solving and transfer.

4.15. The current study: Research questions

On the basis of the rationale provided above, the list of research questions that guided the current study were as follows below (please refer to Appendix L for a graphic representation of the key relationships explored in the study). All questions pertain to participants drawn from a sample of South African university students.

- What is the rate of directed analogical transfer between a given source analogue based on the convergence schema and an isomorphic target problem?
- What is the rate of open analogical transfer between two problem isomorphs presented to participants without a pre-conceived solution strategy?
- What is the nature of the relationship between rates of directed and open analogical transfer between problem analogues given to the same group of participants?
- What are the nature of the relationships between both directed and open analogical problem solving and both verbal and non-verbal analogical reasoning skill?
- What are the nature of the relationships between both directed and open analogical problem solving and self-reported heuristic strategy preference?
- What are the nature of the relationships between both directed and open analogical problem solving and various demographic characteristics (gender, home language, type of schooling, and socioeconomic status)?
- To what extent are verbal and non-verbal analogical reasoning, self-reported heuristic strategy preference, gender, home language, type of schooling, and socioeconomic status predictive of both directed and open analogical problem solving performance?

Chapter 5: Methods

This chapter describes the process followed to collect data for the study, including the overarching research design, the sample, the instruments, the procedure, ethical considerations, and an overview of how the data was analysed.

5.1. Research design

The primary aims of the current study were to establish the nature of the relationships between rates of directed and open analogical transfer and verbal and non-verbal analogical reasoning, self-reported heuristic strategy preference, and several demographic variables (gender, home language, type of schooling, socioeconomic status), as well as to explore the extent to which these latter variables were predictive of analogical problem solving. To achieve these aims, participants were asked to respond to a number of questionnaire-based, self-report measures and tasks; each of these was presented in a standard manner and yielded data that was converted to numerical form for statistical analysis. All of the responses were collected within a relatively short timeframe and none of the key variables were manipulated. There was no formal control group, and no random assignment was carried out. The design of the study was thus classified as quantitative, non-experimental, correlational, and cross-sectional in nature (Cozby & Bates, 2012; Leedy & Ormrod, 2005; Neuman, 2010; Rosenthal & Rosnow, 2008; Salkind, 2006).

The central purpose of this type of design is to provide a framework within which to test expected or proposed relationships between variables drawn from the same group of participants, as well as to explore potential patterns of prediction. Its focus is to observe or capture participant behaviour in a relatively naturalistic manner without direct manipulation or interference; as such it is regarded as a useful approach that is not overly artificial and that can, at least to a degree, reflect everyday occurrences. It is also generally seen as a highly practical strategy that is time and cost effective and not difficult to implement (Cozby & Bates, 2012; Leedy & Ormrod, 2005; Rosenthal & Rosnow, 2008; Salkind, 2006; Stangor, 2015). From a quantitative perspective, however, the lack of control inherent in the approach also represents the design's greatest weakness, namely its inability to support causal conclusions or knowledge claims. This is primarily due to the absence of measures designed to establish temporal precedence and non-spuriousness; the possibility of extraneous factors playing a role in determining the nature of the observed associations or predictions is high and directional inference is extremely difficult (Cozby & Bates, 2012; Leedy & Ormrod, 2005; Rosenthal & Rosnow, 2008; Salkind, 2006; Stangor, 2015). The design is also open to

critiques regarding the practice of quantification (cf. Durrheim, 1999). These include claims that the reduction of data to numerical form constitutes a substantive loss of rich, contextually relevant information that could lead to less nuanced and informed interpretation, as well as concerns regarding the ability of the scores obtained to adequately represent differences or variations in the phenomena under investigation (Babbie & Mouton, 2001; Durrheim, 1999; Murphy & Davidshofer, 2005).

Despite these weaknesses, the design was deemed appropriate to utilise for the current research project given its advantages, the intended purpose of the study (to establish associative patterns), and practical considerations. It was also aligned with the underlying paradigmatic assumptions that informed the research. These were drawn from positivist and post-positivist/critical realist principles and included presumptions of an independent reality, as well as the possibility of identifying generalizable patterns of behaviour through empirical investigation (Stangor, 2015; Terre Blanche & Durrheim, 2006; Trochim, 2006).

5.2. Sample

Given the intended target population (essentially all human beings), there were any number of potential experimentally accessible populations that could have been utilised in the current study (Leedy & Ormrod, 2005; Matthews & Kostelis, 2011). There were also, however, a number of important constraints that guided the final choice as regards type of participant. Certain of these were related to the nature of the instrumentation that was employed. As all of the measures were developed and administered in English in written form, it was necessary to select individuals who were relatively fluent and who could read and write in English with a fair degree of proficiency. In addition, the nature of the tasks was such that respondents were required to adapt to multiple and varied testing demands; this necessitated the selection of individuals with a reasonably high degree of *test-wiseness*, which can be defined as familiarity with and/ or expertise within the realm of assessment and testing, including experience in interpreting and following test instructions (Foxcroft & Roodt, 2001). Another determining factor was the intention to provide data suitable for comparison with international findings; as such, an attempt was made to utilise a similar type of sample to those most commonly employed in the international literature. Lastly, from a practical perspective, it was necessary to select a group that was both accessible to the researcher and sufficiently available to commit to the time required for participation if desired.

Given these considerations, the accessible population that was ultimately selected consisted of students registered for undergraduate or postgraduate degrees at the University of the Witwatersrand, Johannesburg. This group was deemed suitable given their exposure

to formal testing constraints throughout primary and secondary education, a presumed degree of pre-requisite fluency in English based on the medium of instruction at the university, their general accessibility and availability, and similarity to samples used in international contexts (these have typically consisted of undergraduate university students). In addition, this population tends to be highly diverse demographically, including in terms of gender, home language, educational background, and socioeconomic status, thus affording a sufficient degree of variability to ensure the viability of statistical exploration on the basis of these grouping variables.

For ethical and practical reasons, the sampling strategy that was applied was non-probability, haphazard, and convenience sampling, specifically a request for volunteers (Rosenthal & Rosnow, 2008; Salkind, 2006). This approach is regarded as advantageous in terms of ease of application as well as ethical practice, however it does limit external validity as certain participant characteristics may differ from those of the general population (Rosenthal & Rosnow, 2008; 2009; Stangor, 2015; Tredoux & Smith, 2006). In order to compensate for the heavy testing demands placed on participants, the study also employed several motivational strategies to encourage participation (course credit, individual feedback, and entry into a draw for prizes). Whilst the use of incentives is in line with international practice (including within samples used for previous studies in the field of analogical problem solving), it may have further reduced generalisability of the findings on the basis of participant traits (cf. Cozby & Bates, 2012; Rosenthal & Rosnow, 2008; 2009; Stangor, 2015).

For the pilot phase of the study, volunteers were requested from students registered for third year, Honours, and Masters courses in Psychology at the University of the Witwatersrand, Johannesburg. This particular group was selected as they had been exposed to a certain level of psychometric theory and training through their chosen curriculum and were thus able to comment on the suitability of the instrumentation knowledgeably. In addition, as ex-first year students, this group was well placed to judge the appropriateness of the study as a whole for application at a first-year level. For the main phase of the study, volunteers were requested from students registered for first year courses in Psychology at the University of the Witwatersrand, Johannesburg. This group was selected as it is comprised of a large number of students (typically between eight hundred and one thousand in a given year) from a wide range of Faculties and degrees and thus afforded the opportunity to obtain a sizeable, diverse sample which met all of the other criteria outlined above. It is worth noting that even though participation for the main phase of the study was limited to only those registered for study at a first-year level and measurement was carried

out early in the academic year, the potential impact of previous exposure to analogically-based teaching methods (particularly imitative and problem-based learning) remained a concern for generalisability (for all students based on completion of at least twelve years of prior formal education and for certain students from higher levels of study who were only completing the course for credit) (cf. H. Jordaan, personal communication, February 17, 2012). It was, however, not possible to control for this effectively without alerting participants to the purpose of the study and thus biasing their responses (Rosenthal & Rosnow, 2008; Stangor, 2015).

For the pilot phase of the study, a final sample of 43 participants was obtained. Of these, 8 (19%) were male and 35 (81%) were female; the average age was 22.8 years with a standard deviation of 3.1. The vast majority of these participants were registered in the Humanities (36 (84%)); 4 (9%) were from Science, 2 (5%) from Commerce, and 1 (2%) from Engineering and the Built Environment. Eighteen (42%) were studying at an undergraduate level, 12 (28%) at an Honours level, and 13 (30%) at a Masters level. Twenty-four (56%) participants self-identified themselves as White, 9 (21%) as Black, 8 (19%) as Indian, 1 (2%) as Coloured, and 1 (2%) as Asian. English was listed as a home language by 37 (86%) of these participants, the remainder identified isiZulu (2 (5%)), Afrikaans (1 (2%)), isiXhosa (1 (2%)), Sesotho (1 (2%)), and Xitsonga (1 (2%)) as their home languages respectively. Thirty-five (81%) identified English as the medium of instruction for their primary education and 36 (84%) identified English as the medium of instruction for their secondary education; 25 (58%) were educated through the private (independent) school system in contrast to 18 (42%) who were educated through the government school system. All participants identified their self-rated understanding, reading, and writing in English as good or excellent, and 34 (79%) reported a maximum level of reading access (reading fiction and non-fiction by both self and family). Forty (93%) of these participants had complete access to living standards resources such as electricity, hot water, and electrical appliances, and 36 (84%) had high levels of access to technology (for example, PC, laptop, TV, landline telephone). These factors, in conjunction with parental education and parental occupation, were used as the basis for categorising socioeconomic status; however this was artificially structured to form three groupings within the sample, thus the descriptive statistics for each level are not particularly informative (each being approximately 33% by design). For a full breakdown of all demographic characteristics relevant to this sample, please refer to Table B.1 and Table B.2 in Appendix B.

For the main phase of the study, approximately 850 questionnaire packs were distributed to potential participants; of these, 681 were returned, representing a response

rate of 80.1%. The most likely explanation for this rate, which was unusually high, was the introduction of course credit for participation, which was piloted with students registered for first year Psychology modules in the year data was collected for the first time. The timing of the administration, which occurred very early in the academic year, may have also acted as a contributing factor. As detailed in Table 5.1, of the 681 questionnaires that were returned, 23 (3%) were excluded from analysis due to too high a level of missing data, and 658 (97%) were retained. Within the set of questionnaires that was retained, 566 (86%) were fully complete and 92 (14%) were missing at least one key measure or task. Specifically, 50 (7%) respondents did not complete the task assessing directed transfer, 66 (10%) did not complete the task assessing open transfer, and 9 (1%) did not complete the measure of heuristic strategy preference. There was, however, a degree of overlap between these missing measures (for example 27 (4%) respondents omitted both the directed and open transfer tasks) thus only 92 questionnaire packs in total were incomplete. It is also important to note that even within the group of complete questionnaire packs, various respondents omitted single or small sets of items across the full range of measures, which resulted in further sample size variations for different analyses.

Table 5.1

Main phase: Excluded and included questionnaire packs (N = 681)

	n	%	Missing data
Excluded	23	3.38	
questionnaire packs	14	2.06	Directed transfer, open transfer, heuristic strategy preference, verbal analogical reasoning
	1	0.15	Directed transfer, open transfer, verbal analogical reasoning
	5	0.73	Directed transfer, open transfer, heuristic strategy preference
	3	0.44	All demographics
Included questionnaire	658	96.62	
packs	50	7.34	Directed transfer
	66	9.69	Open transfer
	9	1.32	Heuristic strategy preference

Of the 658 final participants whose responses were included, 171 (26%) were male and 487 (74%) were female; the average age was 19.1 years with a standard deviation of

2.1. A large number of the participants were registered in the Humanities (452 (69%)), followed by 121 (18%) from Science, 55 (8%) from Commerce, and 24 (4%) from other faculties. The vast majority of these participants (606 (92%)) were first-year level students; the remaining 52 (8%) were higher level undergraduate students completing the module for credit purposes. Three hundred and five participants (47%) self-identified themselves as Black, 229 (35%) as White, 67 (10%) as Indian, 50 (8%) as Coloured, and 6 (1%) as Asian. Three hundred and seventy-eight (57%) participants listed English as their home language, followed by isiZulu (83 (13%)), Sesotho (36 (6%)), Setswana (36 (6%)), Sepedi (35 (5%)), Afrikaans (21 (3%)), and isiXhosa (18 (3%)) as the most commonly identified home languages. English was identified as the medium of instruction for primary education by 481 (73%) participants and as the medium of instruction for secondary level education by 477 (73%) participants; 343 (52%) were educated through the government school system in contrast to 292 (44%) who were educated through the private (independent) school system (23 (4%) responses were missing). Over 90% of participants identified their self-rated understanding, reading, and writing in English as good or excellent; the remainder described their abilities as average. A maximum level of reading access (reading fiction and non-fiction by both self and family) was reported by 317 (48%) of these participants. Four hundred and seventy-two (72%) of these participants had full levels of access to living standards resources such as electricity, hot water, and electrical appliances, and 406 (62%) had high levels of access to technology (for example, PC, laptop, TV, landline telephone). As in the pilot sample, these factors were used in conjunction with parental education and parental occupation to create three categorisations of socioeconomic status; thus approximately 33% of the sample group fell into each socioeconomic category (low, average, and high). For a full breakdown of all demographic characteristics relevant to this sample, please refer to Table B.3 and Table B.4 in Appendix B.

5.3. Instruments

Data was collected through administration of a questionnaire pack that contained the following measures/ tasks: a demographic questionnaire, a task assessing directed analogical transfer/ problem solving, a task assessing open analogical transfer/ problem solving, the *Raven's Advanced Progressive Matrices (RAPM)* as a measure of non-verbal analogical reasoning, a self-developed verbal analogical reasoning task (four-term verbal analogies), and an adapted measure of self-reported heuristic strategy preference. For the pilot study, an additional questionnaire assessing the effectiveness and appropriateness of the instrumentation and feasibility of the study as a whole was developed and administered.

5.3.1. Demographic questionnaire (please refer to Appendix F)

A detailed self-developed *demographic questionnaire* was utilised to obtain data relevant to describing the sample and addressing certain of the research questions posed. The information requested included: age, gender, race, year and area of study at university, home language, type of schooling experienced (including language/s of education), self-estimated English fluency, reading access, socioeconomic status, and modal preference.

Socioeconomic status was estimated using parental occupation and education - adapted from the Barrett Simplified Measure of Social Status (Barrett, 2006), as well as reported levels of access to living standards resources and technology - adapted from the Living Standards Measure (Haupt, 2006). For the latter questions, participants were asked to indicate whether various resources or appliances were present in their home environment while they were growing up; these included electricity, hot water, a fridge/ freezer, an electric stove, a television, a computer, and a landline telephone.

Modal preference, the manner in which a person prefers to receive information they are required to learn or utilise, was assessed using the Modal Preference subscale of the Canfield Learning Styles Inventory (Canfield, 1980, as cited in Pettigrew & Buell, 1989; Matthews, 1991; Pettigrew & Buell, 1989). This subscale consists of six items, each of which contains four options representing four distinct modal preferences (listening, reading, iconic (visual), and direct experience) (Canfield, 1980, as cited in Pettigrew & Buell, 1989; Canfield, 1992, as cited in Stitt-Gohdes, 2001; Matthews, 1991). Respondents are required to rank each of the four options in each item from 'most preferred (1)' to 'least preferred (4)', thus creating a profile of modal preference consisting of four total scores ranging from 6 to 24 (Canfield, 1992, as cited in Stitt-Gohdes, 2001). There is considerable debate regarding the psychometric properties of the Canfield Learning Styles Inventory as a whole, including issues related to both reliability and construct validity. There is, however, agreement that the scale has excellent face validity and provides useful feedback to both students and instructors that matches with their expectations (Sewall, 1986; Stitt-Gohdes, 2001). In addition, internal reliability estimates for the subscales have typically been found to be fairly high, ranging between 0.86 and 0.96 in most cases (Pettigrew & Buell, 1989; Stitt-Gohdes, 2001). Modal preference was included in the questionnaire primarily as part of the motivational manipulation to encourage participation (individual feedback). It was, however, also potentially useful to consider as an additional demographic factor, particularly as all of the measures/ tasks were presented to participants in written form.

5.3.2. Directed analogical transfer task. (please refer to Appendix F)

The task used to assess directed (prompted) transfer in the current study adopted the basic procedure that was developed by Gick and Holyoak (1980; 1983). This has been widely utilised in previous studies (cf. for example, Anolli et al., 2001; Antonietti & Gioletta, 1995; Beveridge & Parkins, 1987; Catrambone et al., 2006; Catrambone & Holyoak, 1989; Corkill & Fager, 1995; Cushen, 2012; Cushen & Wiley, 2018; Edwards et al., 2014; Francis, 1999; Hostetter et al., 2018; Keane, 1985; Klein, 1994; Kubricht et al., 2015; Kurtz & Loewenstein, 2007; Needham & Begg, 1991; Pedone et al., 2001; Peterson & Wissman, 2018; Spencer & Weisberg, 1986) and consists of presenting participants with at least one source analogue (problem and solution) at an earlier point in time, often in disguised form, and then at least one target analogue (problem to be solved) at a later point in time. This ensures that participants are exposed to a relevant solution principle or schema and allows the researcher to track rates of spontaneous and directed (prompted) analogical transfer through withholding or providing a hint as regards the relevance of the source for solving the target successfully (Anolli et al., 2001; Corkill & Fager, 1995; Cushen, 2012; Gick & Holyoak, 1980; 1983; Richland & McDonough, 2010). In the current study, participants were presented with a source passage disguised as a reading comprehension exercise, followed by an intervening task (the verbal analogical reasoning measure), and then presentation of the target analogue as a creative problem solving exercise (all in written form as part of the questionnaire pack to be completed) (cf. Catrambone & Holyoak, 1989).

In order to maximise comparability with international studies, the underlying schema for transfer that was used was the 'convergence schema' (cf. Gick & Holyoak, 1980; 1983; Zook, 1991) represented in Duncker's classic radiation problem and numerous analogues such as the general, the fire chief, the aquarium, the lightbulb, the artificial lake etc... (please refer to Appendix A). This solution involves sending less powerful entities along multiple paths surrounding a central object simultaneously to create a more powerful, combined central force (Antonietti & Gioletta, 1995; Catrambone & Holyoak, 1989; Corkill & Fager, 1995; Gick & Holyoak, 1980; 1983; Holyoak & Koh, 1987; Hostetter et al., 2018; Klein, 1994; Kubricht et al., 2015; Zook, 1991). Although the ideal target to be solved would have been the radiation problem itself, this was cited and explained in the textbook assigned to the first year Psychology modules from which the sample was drawn. A lesser well known analogue - the aquarium problem developed by Catrambone and Holyoak (1989) - was thus used as the target instead.

As rates of spontaneous transfer are typically very low (cf. Anolli et al., 2001; Bearman et al., 2002; Catrambone & Holyoak, 1989; Francis, 1999; Hostetter et al., 2018;

Kubricht et al., 2015; Markman et al., 2007; Monaghan et al., 2015; Novick & Holyoak, 1991; Reeves & Weisberg, 1994; Richland & McDonough, 2010), and given that multiple exemplars have been shown to facilitate analogical transfer and schema induction (cf. Bearman et al., 2002; Billing, 2007; Catrambone & Holyoak, 1989; Chen & Mo, 2004; Gentner et al., 2003; Gick & Paterson, 1992; Klein, 1994; Kurtz & Loewenstein, 2007; Novick & Holyoak, 1991; Reeves & Weisberg, 1994; Thomas, 2008), participants were provided with two source analogues. These were slightly adapted versions of the general and the fire chief analogues originally developed by Gick and Holyoak (1980; 1983); in the current study one was embedded within the other in the guise of a story where the general resolved his difficulty of gaining access to the dictator's fortress through remembering how a fire in his home village was extinguished (cf. Gick & Holyoak, 1983). This source passage (including how both situations were resolved) was followed by four comprehension questions designed to highlight central aspects of the shared solution strategy; these also constituted a possible basic measure of the quality of the schema induced and acted as a form of retrieval practice (cf. Catrambone & Holyoak, 1989; Corkill & Fager, 1995; Gick & Holyoak, 1980; Hostetter et al., 2018; Peterson & Wissman, 2018).

In addition to being less well known than the radiation problem itself, all three analogues utilised in the current study were chosen as they were felt to be less likely to be perceived as requiring specialist knowledge to address. This assumption is in line with findings produced by Corkill and Fager (1995), who showed that participants rated the radiation and lightbulb analogues as less familiar and more technical than the general and the fire chief analogues. Both of these latter analogues (the general and the fire chief) have also been used relatively extensively as sources within international experimental studies exploring analogical problem solving (cf. Catrambone et al., 2006; Catrambone & Holyoak, 1989; Corkill & Fager, 1995; Cushen, 2012; Edwards et al., 2014; Gick & Holyoak, 1980; 1983; Hostetter et al., 2018; Keane, 1985; Klein, 1994; Kurtz & Loewenstein, 2007).

Although there are minor differences across different source-target combinations, core aspects of the convergence schema are typically seen to consist of: the initial use of multiple forces or sources of lesser or weaker intensity, application of these to a central object from different directions (surrounding the central object), simultaneous application, and convergence to create a more powerful combined force or source from the smaller or weaker components (cf. Antonietti, 1996; Antonietti & Gioletta, 1995; Catrambone et al., 2006; Catrambone & Holyoak, 1989; Cushen, 2012; Cushen & Wiley, 2018; Gick & Holyoak, 1980; 1983; Hostetter et al., 2018; Kubricht et al., 2015; Novick & Holyoak, 1991; Peterson & Wissman, 2018). In previous studies, classification of participant solutions as analogical has

depended on the extent to which certain of these core features were deemed to be present, with slight variations. For example, Gick and Holyoak (1980) scored solutions as completely analogical if they contained the feature of different directions and either simultaneous application or lower intensity. In contrast, Cushen (2012) required that all three of these elements (which he termed use of weak forces, spatial convergence, and temporal convergence) were present for the solution to be deemed fully analogical. Kubricht et al. (2015) altered the composition of the components slightly; for solutions to be deemed analogical they required the presence of two of three core features (multiple sources, low intensity, and positioning around the target in different locations). Antonietti and Gioletta (1995) also adopted a slightly different approach; they identified four core features (low intensity, circular disposition, simultaneous application, and summation at a central convergence point), and required three of these to be present for the solution to be categorised as fully analogical (one or two features constituted a partial analogical solution).

Given its marginally higher level of sophistication, as well as its ability to allow for appropriate distinctions between aspects of the convergence schema as applied specifically to the aquarium analogue to be made (for example, the situating of lights above or outside the tank, the use of dimmer or less powerful or different types of lights, alterations to location of the lights, and the form of focus on the replica required), the scoring framework developed by Antonietti and Gioletta (1995) was applied in this study. Specifically, solutions were classified as partially analogical if the features of reduced intensity or multiple lights were present, and were classified as completely analogical if, in addition to these, participants also incorporated either the notion of circular disposition or simultaneous application (simultaneous summation) or both. Participant responses that contained none of these features were classified as non-analogical (please refer to Chapter 6 for additional detail). A form of inter-rater reliability (percentage agreement with an independent coder) for coding of the responses was established in the pilot study.

It is important to note that although eventually implemented as a measure of directed transfer, this task was initially conceptualised as a measure of spontaneous analogical transfer. However, even with the presence of two source analogues, rates of transfer obtained during the pilot study where no hint was given regarding the relevance of the comprehension exercise for the creative problem solving exercise were so low (7 participants of 43 representing 16%) that this became problematic given the intended aims of the study as a whole. As a result, for the main administration, a general hint was added as part of the instructions for the creative problem solving exercise. This hint suggested that participants might find it useful (although not strictly necessary) to consider the previous

story of the general described in the comprehension when attempting to think of solutions to the problem of lighting the aquarium.

5.3.3. Open analogical transfer task. (please refer to Appendix F)

In order to assess open analogical transfer, participants were asked to provide as many solutions as possible for two additional problems. Each of these was presented as an independent creative problem solving exercise in the questionnaire pack and the two were separated by an intervening task (the self-reported heuristic strategy preference measure). No solution was provided for either problem, and there was no overt hint or information included that suggested a link between the two tasks. There was also no strict requirement regarding the order in which the two problems needed to be addressed. Although one was printed in the questionnaire pack before the other (and was thus more likely to be answered first), participants were free to complete the exercises in whichever order they chose or to modify their answers further after attempting both tasks.

The two problems that were utilised were both adapted from Chen and Daehler (1989). In the first, which itself is an adaptation of an Aesop's fable (The Crow and the Pitcher), a thirsty bird cannot reach the water contained in a bottle as the level is too low and the neck of the bottle too narrow. In the second, a group of boys cannot retrieve their ping-pong ball which has become trapped in a hole in the wall. Chen and Daehler (1989) identified one potential analogical solution strategy that could be shared between these problems. This solution draws on the classic solution implemented by the crow in Aesop's fable and consists of adding an additional object or substance to make the desired object rise and thus become more accessible (in the case of the water, stones; in the case of the ping-pong ball, water). It is critical to note that although the existence of this strategy ensured that the two problems shared a sufficient degree of structural similarity for analogical transfer to be possible (cf. Bassok, 2003; Gentner & Colhoun, 2010; Gentner & Smith, 2012; Yanowitz, 2001), no presumption was made regarding which type of solutions would constitute analogical responses to these tasks until after analysis of participant responses was carried out. In addition, both problems dealt with relatively familiar, non-technical scenarios and were deemed likely to permit a wide range of possible solutions.

Although the procedure used was similar to the one implemented by Gick and Holyoak (1980) in their third experiment in which participants were presented with both the radiation problem and the general analogue but were not given the underlying schematic principle (or an overt solution strategy), there were also a few critical differences. Specifically, no hint was given regarding a potential link between the two problems, the order

of solution was not specified, and, most importantly, decisions regarding whether analogical transfer occurred or not were taken only after analysis of the responses given and careful evaluation of potential shared structural similarity between the different content categories. In this way, it was hoped that restriction on the basis of pre-ordinate assumptions by the researcher regarding which principles or strategies represented analogical transfer would be avoided (cf. Day & Goldstone, 2012; Lave, 1988; Lobato, 2006; Nokes, 2009). Respondents were also permitted to draw on the full scope of their pre-existing knowledge and experience when attempting to solve the two problems – it was hoped that this would provide a more naturalistic representation of the process undertaken in real-world learning, occupational, and social environments (cf. Antonietti, 1996; Day & Goldstone, 2012; Holyoak, 2012; Lave, 1988; Lee, 1992; Novick & Holyoak, 1991).

It is worth noting that possible previous exposure to either of the analogues (including exposure to commonly identified solution strategies) was not deemed problematic as the variable of interest was not the solution itself, but whether a corresponding principle or schema underpinning the solutions given to both problems could be identified, thereby constituting evidence of analogical transfer. It is also important to note that this process of identification was both highly inferential and retrospective, which does raise potential methodological concerns. As with the directed transfer task, a form of inter-rater reliability (percentage agreement with an independent coder) for coding of the responses was established in the pilot study. Despite this, the method is a novel one and will require further interrogation and replication to establish its robustness.

5.3.4. Raven's Advanced Progressive Matrices. (please refer to Appendix F)

The *Raven's Advanced Progressive Matrices (RAPM)* constitute a highly established psychometric instrument designed to assess eductive ability, "...a person's capacity to form comparisons, reason by analogy, and develop a logical method of thinking, regardless of previously acquired information" (Raven, 1938, p.12, as cited in Paul, 1985, p.95) in adult samples of above average intelligence (Raven, 2000; Raven et al., 1998). The test consists of a series of geometrically-based reasoning tasks which require respondents to infer and then complete the underlying, complex structural pattern or progression sequence represented in each item (Carpenter et al., 1990; Kunda, McGreggor, & Goel, 2013; Raven et al., 1998; Rasmussen & Eliasmith, 2014; Schweizer, Goldhammer, Rauch, & Moosbrugger, 2007). As such, and in addition to being widely recognised as one of the best single measures of *g* (general intelligence) available, the *RAPM* are also considered a quintessential measure of non-verbal analogical reasoning (Antonietti & Gioletta, 1995; Correa, Prade, & Richard, 2012; DeShon, Chan, & Weissbein, 1995; Harrison, Shipstead, &

Engle, 2015; Kunda et al., 2013; Kubricht et al., 2015; Mackintosh & Bennett, 2005; Primi, 2001; Raven et al., 1998).

The *RAPM* are comprised of two sets of items. The first set, which contains twelve questions, is designed to allow participants the opportunity to familiarise themselves with the demands of the test and practice the response format, thus avoiding underestimation due to a lack of test-wiseness. The second set, consisting of thirty-six items, is used to formally measure the construct of interest (Babcock, 2002; Raven et al., 1998). Each item in either set consists of a matrix of nine cells, eight of which contain a geometric pattern which varies according to the number and type of shapes included, their size and orientation, background shading, or other visual elements. Participants are required to induce the appropriate answer that completes the pattern in the ninth cell from eight alternatives through correctly identifying and extending the shifts or changes in patterns represented in the previous blocks (Bors & Stokes, 1998; Brouwers et al., 2009; Carpenter et al., 1990; Kunda et al., 2013; Meo et al., 2007; Paul, 1985; Raven, 2000; Raven et al., 1998; Rushton et al., 2003). All of the questions contained in the *RAPM* are thus self-report, closed-ended, performance-based, and multiple choice in nature. Respondents receive a final score out of twelve for Set I and out of thirty-six for Set II. The test can be administered either individually or to a group of respondents under either timed or untimed conditions (Raven et al., 1998). In the current study, participants were provided with an adapted form of group training for Set I piloted by Israel (2006); and were then asked to complete Set II under untimed conditions within a group venue (please refer to Section 5.4.2 for additional detail).

Internal consistency reliability estimates for the *RAPM* have been found to be strong, typically ranging between 0.8 and 0.92 (cf. Alderton & Larson, 1990; Bors & Stokes, 1998; Israel, 2006; Paul, 1985; Raven et al., 1998; Rushton et al., 2003; Taylor, 2008; Vigneau & Bors, 2008; Wiley, Jarosz, Cushen, & Colflesh, 2011). The *RAPM* have also been shown to exhibit good test-retest reliability, with estimates typically ranging between 0.76 and 0.9 (cf. Bors & Stokes, 1998; Bors & Vigneau, 2003; Kaplan & Saccuzzo, 2001; Raven et al., 1998; Spreen & Strauss, 1998). As expected, overall scores for the *RAPM* have been shown to correlate with scores on measures of working memory, processing speed, and other tests of intelligence, suggesting good convergent construct validity (cf. Harrison et al., 2015; Raven et al., 1998; Tamez, Myerson, & Hale, 2008; Unsworth & Engle, 2005; Verguts & De Boeck, 2002). The internal structure of the scale has also been largely supported through multidimensional scaling and factor analytic studies (cf. Alderton & Larson, 1990; Arthur & Woehr, 1993; DeShon et al., 1995; Snow, Kyllonen, & Marshalek, 1984, as cited in Carpenter et al., 1990). The test has been widely applied across a range of geographic

locations, settings, and populations (cf. Kunda et al., 2013; Paul, 1985; Rasmussen & Eliasmith, 2014; Raven et al., 1998; Taylor, 2008), and, although subject to potential cultural biases, is still considered to “...show less influence of confounding cultural factors on the [sic] cross-national differences than any other intelligence test...” (Brouwers et al., 2009, p. 330).

5.3.5. Verbal analogical reasoning task. (please refer to Appendix F)

Although several existing measures of verbal analogical reasoning were evaluated for use in the study, these proved to be impractical and/or inappropriate for the chosen sample group and South African context. Reasons for this included: restricted access and associated costs, required conditions for administration, required level of linguistic proficiency, and concerns regarding possible cultural and linguistic bias. As a result, and in line with common practice by other researchers working in the area, a self-developed *verbal analogical reasoning task* was compiled by the researcher in order to assess participants' verbal analogical reasoning skills (cf. Bejar et al., 1991; Embretson, Schneider, & Roth, 1986; Goldman, Pellegrino, Parseghian, & Sallis, 1982; Green et al., 2012a; Harpaz-Itay et al., 2006; Kahney, 1993; Kao, 2014; Kostic et al., 2010; Richland et al., 2010; Sternberg, 1977; 1983; Vendetti et al., 2014b).

In order to create the task, a pool of possible items (each in the form of a classic four-term verbal analogy) was compiled from a variety of published sources (cf. Embretson & Schneider, 1989; Green et al., 2006; Kahney, 1993; Marr & Sternberg, 1986; Monson & Dawis, 1975; Morrison, 2004; Sheard & Readance, 1988; Sternberg, 1983; Zook, 1991). Each item in the pool was then classified according to the relation type represented based on a combination of the types structures identified by Kahney (1993), Pellegrino and Glaser (1982), and Whitely (1976); representation of a range of types in the measure was felt to be important as the limited evidence available suggests that different relational types may be associated with different sets of cognitive skills (cf. Kahney, 1993; Whitely, 1976). Each item was then evaluated as to whether it would be appropriate for use in the South African context as regards cultural and linguistic content. Ultimately thirty-two items were selected for the task in the following relation-type categories: *synonyms* (3 items); *antonyms* (3 items); *difference of degree* (2 items); *part-whole* (2 items); *function* (4 items); *conversion* (3 items); *class-member* (3 items); *property* (5 items); *location* (4 items); and *structural* (3 items).

The task presented to participants thus consisted of thirty-two four-term analogies, each of which was presented in the form of a three-term stem and missing fourth term (A is

to B as C is to ? (D omitted)). Respondents were asked to select the most appropriate option to complete the missing fourth term from six choices (five distractors and one correct answer). The format of the *verbal analogical reasoning task* was thus identical to that of the *Raven's Advanced Progressive Matrices*, in that it was self-report, closed-ended, performance-based, and multiple choice in nature. Scores on the task were calculated by adding the number of correct responses, allowing for a maximum theoretical score of 32. As the task was self-developed, its psychometric properties (including the potential for ceiling effects) were unknown prior to analysis of the results of the study.

5.3.6. Self-reported heuristic strategy preference measure. (please refer to Appendix F)

As no existing direct measure of the construct of interest could be sourced, self-reported heuristic strategy preference (including preference for adopting analogy as an overt heuristic strategy) was assessed using an adapted version of the *Problem Solving Strategy Questionnaire* developed by Antonietti et al. (2000).

The original questionnaire contains short paragraph descriptions of five problem-solving strategies - free production, step-by-step analysis, analogy, visualization, and combining (please refer to Appendix A). For each strategy, respondents are asked to rate the frequency with which they apply the strategy, their opinion of its utility, and their perception of its ease of application for interpersonal, practical, and study problems on a five-point scale (Antonietti et al., 2000).

For the adapted measure, which focussed only on preferred approaches to solving academic and/or practical problems, the paragraph descriptions for each strategy from the original questionnaire were split into three shorter sentences. An additional statement for each strategy was also formulated based on available theory (Antonietti et al., 2000; Buchtel & Norenzayan, 2008; Güss & Wiley, 2007; Koichu et al., 2003; Metallidou & Platsidou, 2008). The total pool of items thus consisted of twenty independent short statements, each representing a distinct problem-solving method or behaviour based within one of the five broader classic strategies described by Antonietti et al. (2000). Participants in the study were asked to indicate how often they applied the approach represented in the item when attempting to solve an academic and/or practical problem on a five-point, Likert-type scale ranging from 'Never (1)' to 'Always (5)'. Higher scores for an item indicated a greater use of and thus preference for that particular behaviour or method. Although designed to represent aspects of the five strategies identified by Antonietti et al. (2000), the internal structure

(including the overarching scoring framework) and psychometric properties of the adapted measure were unknown prior to analysis of the results of the study

5.3.7. Pilot study questionnaire. (please refer to Appendix F)

For the pilot study, an additional questionnaire assessing respondent perceptions of the feasibility of the proposed procedure and appropriateness of the measures contained in the questionnaire pack (excluding the Raven's Advanced Progressive Matrices) was developed and administered. Specific information requested included: time taken to complete the questionnaire pack; whether or not assistance was requested at any point; the extent to which the instructions were easy to understand and follow; identification of any items that were found to be difficult to answer due to language, content, or context; opinion of whether other students would be likely to volunteer to participate in the study or not; perceptions of the feedback provided; and any additional information that the respondent felt would be useful to add.

5.4. Procedure

5.4.1. Permission and piloting.

Permission to conduct the study was obtained from both the Higher Degrees Committee of the Faculty of Humanities at the University of the Witwatersrand and the University of the Witwatersrand Human Research Ethics Committee (Non-Medical) (protocol number: H120406) (please refer to Appendix C).

Once permission was granted, selected classes of students registered for third year, Honours, and Master of Arts degrees in the Department of Psychology were approached and invited to participate in the pilot phase of the study with permission from relevant course coordinators and lecturers (please refer to Appendix D). Students in these classes were advised verbally of the nature of the study, the requirements for participation, and that choosing to participate was completely voluntary. Those students who were willing to participate were provided with a full participant information sheet (please refer to Appendix D), and a questionnaire pack consisting of the *demographic questionnaire*, the original *spontaneous analogical transfer task* (presented as a reading comprehension exercise followed by a separate creative problem solving exercise), the *verbal analogical reasoning task*, the *open analogical transfer task* (presented as two separate exercises in creative problem solving), and the *self-reported heuristic strategy preference measure*. The *Raven's Advanced Progressive Matrices* were not included in the pilot study due to both practical

constraints (time and administration requirements) and the test's relatively well-established psychometric properties, including in the South African context (cf. Cockcroft & Israel, 2011; Israel, 2006; Raven et al., 1998; Rushton et al., 2003; Taylor, 2008).

Participants were also given a copy of the *pilot study questionnaire* and were asked to complete this once they had completed the full questionnaire pack; this was necessary as many of the questions asked required the participant to reference the tasks or measures in the questionnaire pack. They were given the option of completing the questionnaire pack in one of several testing sessions held on campus over a six week period or at home in their own time within the same timeframe. This was possible as all of the measures in the questionnaire pack were either self-developed or freely available, and instructions for each of these could be provided in written form. Participants were asked to keep track of the time taken to complete the full questionnaire pack and ideally to complete this in a single sitting if possible. It was emphasised to participants that completion of the questionnaire pack without assistance was vital to the purpose of the study, and they were asked to indicate whether they had asked for any help from someone else while completing the pack in the *pilot study questionnaire*.

Given the length of the questionnaire pack and concomitant time commitment, participants were offered two incentives for participation – entry into a draw for prizes and individual feedback regarding modal preference designed to assist students with their learning in the university environment (please refer to Appendix E). In order to obtain contact details for entry into the draw, a detachable sheet requesting participants' name, telephone number, and email was included at the front of the questionnaire pack (please refer to Appendix E). Participants were asked to fill this sheet in, detach it, and submit it separately to their completed questionnaire pack in order to preserve the anonymity of their data. Each page in the questionnaire pack (including the participant information sheet) was also marked with a random four-digit participant code. Participants were asked to make a special note of this number, which functioned both as a means of identification and confirmation of participation in the draw for prizes, and as a mechanism for providing feedback whilst preserving anonymity. One of the questions asked in the *pilot study questionnaire* pertained to the perceived efficacy of this feedback. For this reason, participants were asked to complete and return the questionnaire pack to a sealed box located in a central, accessible venue; to wait several weeks to collect their feedback; and to then complete this final question. Ultimately very few participants returned to collect their feedback; the vast majority completed the *pilot study questionnaire* at the same time as the main questionnaire pack

and returned the two simultaneously with the question regarding the efficacy of the feedback omitted.

Once data collection for the pilot study was complete, the responses received were analysed and minor adjustments made to improve the efficacy of the instrumentation and procedure for the main study.

5.4.2. Primary Data Collection.

In order to accommodate administration of the *Raven's Advanced Progressive Matrices* (these constitute a copyrighted test that may not be administered without strict supervision and require the opportunity for training/ practice with Set I), data collection for the main study was divided into two stages. In the first stage, participants were asked to complete both Set I and Set II of the *Raven's Advanced Progressive Matrices*, as well as the adapted training for the test. In the second stage, participants were asked to complete the remainder of the measures in the questionnaire pack in their own time and to return this when complete. The first stage was primarily conducted in large group settings (although a few participants completed this stage individually under the supervision of the researcher) and lasted for approximately an hour to an hour-and-a-half in each instance. For the second stage, participants were asked to complete and return the full questionnaire pack within a timeframe of two to three weeks. All of the data for the main phase of the study was collected over a three month period at the start of the academic year (February to April).

After completion of the pilot phase, permission to approach students registered for first year level modules in Psychology in order to invite them to participate in the study was obtained from the Head of Department, first-year level course coordinator, and first-year level lecturers (please refer to Appendix D). Once this was obtained, students were approached briefly before their class began or during a break and were verbally invited to volunteer to participate in the study. They were clearly informed of the aims of the study; that participation would be completely voluntary; that the data collected would be anonymous; and that returning a completed questionnaire would be regarded as informed consent to participate in the study. They were also advised of the requirements for participation (attendance of a face-to-face testing session lasting approximately an hour as well as completion of the remainder of the questionnaire pack in their own time) and of the potential risks (none foreseeable) and benefits (course credit, individual feedback, and entry into a draw for prizes). Students who elected to participate were asked to attend one of several pre-arranged testing sessions or to contact the researcher to organise an appropriate time for completion of the first stage of data collection.

Those students who arrived to complete the first stage were provided with a questionnaire pack that contained the *demographic questionnaire*, the answer sheets for the *RAPM Set I* and *Set II*, the comprehension (source) component of the *directed analogical transfer task*, the *verbal analogical reasoning task*, the creative problem solving (target) component of the *directed analogical transfer task*, the first creative problem solving exercise for the *open analogical transfer task*, the *self-reported heuristic strategy preference measure*, and the second creative problem solving exercise for the *open analogical transfer task*. The order of the measures was carefully chosen to facilitate completion as well as to partially mask the direct links between the analogical tasks. At the front of the questionnaire pack, participants were provided with a detailed participant information sheet that they were asked to read carefully, and to then detach and keep if they wished to continue with the study (please refer to Appendix D). In addition, the front of the pack contained the detachable sheet requesting contact details for entry into the draw. As in the pilot study, each page of the questionnaire pack was also marked with a random four-digit participant code for the purposes of identification and feedback whilst preserving anonymity.

A third incentive for participation, an additional course credit of 1% for the Psychology One module, was also offered to students. This was carried out in line with a larger Departmental project exploring the feasibility of offering undergraduate students credit in return for research project participation (an option not implemented previously). The parameters for this, implications, and mechanisms put in place to preserve anonymity were clearly presented to potential participants in a separate information sheet, and those students who wished to receive credit were asked to complete and submit a separate form containing their student number and course codes ((please refer to Appendix E). The form containing the student number was not labelled with the random four-digit participant code and could thus not be linked to the data provided by the participant for the study.

After participants had read the participant information sheet and elected to continue with the study, they were provided with the test booklet for the *Raven's Advanced Progressive Matrices Set I* and *Set II*, and completed the adapted group training. Once they had completed *Set II* under untimed conditions, they were asked to hand back the test booklet containing the items and to take the questionnaire pack home to complete in their own time (participants were offered the possibility of continuing to complete the full questionnaire pack if they wished to do so however no participants chose to pursue this option). They were asked to return the completed questionnaire pack to one of several

sealed boxes placed in central locations within the Psychology Department within a timeframe of two to three weeks.

After questionnaires had been returned, all completed forms containing the required participant details were collated for entry into the draw. Individual feedback for participants was also generated and recorded by participant number. Although very few participants collected their individual feedback, this was at least partly expected given a similar situation in the pilot phase of the study as well as an unavoidable delay in processing of the feedback for the main study due to the unanticipated high response rate. Once data collection for the main phase of the study was complete, the responses received were captured electronically and analysed.

5.5. Ethical considerations

The study conformed to accepted ethical standards for research (cf. HPCSA, 2003; Leedy & Ormrod, 2005; Rosnow & Rosenthal, 2013) and received full clearance from the University of the Witwatersrand Human Research Ethics Committee (Non-Medical) (protocol number: H120406) (please refer to Appendix C). In order to ensure that there was informed consent (HPCSA, 2003; Rosnow & Rosenthal, 2013), potential participants for both the pilot and main study were provided with a verbal explanation of what the study would entail as well as a detailed participant information sheet once they had elected to participate (please refer to Appendix D). This sheet included: an introduction outlining who the researcher was and the intended aim of the study; an invitation to participate; a clear explanation of the requirements for participation; an explanation of the voluntary nature of participation and anonymity of the data; an outline of the benefits for participation (individual feedback and entry into a draw for all participants, as well as course credit for all participants in the main phase of the study) and potential risks (none foreseeable); information regarding data protection and storage, feedback, queries, and contact details for the researcher and research supervisor; and a clear statement emphasising that return of the completed questionnaire would be considered as informed consent to participate in the study.

Anonymity of the participants (HPCSA, 2003; Rosnow & Rosenthal, 2013) was maintained as no directly identifying information was requested within the questionnaire pack itself. Both the sheet requesting personal details for entry into the draw and the sheet requesting student number for credit purposes (please refer to Appendix E) were detached and separated from the questionnaire pack prior to and during submission of the completed questionnaires by participants. Linking of information for feedback purposes and the draw

was done through a randomly assigned four-digit code. Data was also kept strictly confidential (HPCSA, 2003; Rosnow & Rosenthal, 2013) as completed questionnaires were stored securely in a location with limited access and were processed only by the researcher.

As clearly indicated to participants, there were no potential foreseeable risks as a result of participating in the study, and no negative outcomes were indicated by any participant. As detailed in the participant information sheet, participants were offered direct benefits (individual feedback and entry into a draw for all participants and course credit for participants in the main phase of the study). These were deemed commensurate with the requirements for participation and non-coercive by the University of the Witwatersrand Human Research Ethics Committee (Non-Medical) and were not reported as being perceived as inappropriate by any participant. There was also no deception of participants, and none of the information requested was deemed particularly sensitive.

Debriefing (HPCSA, 2003; Rosnow & Rosenthal, 2013) was carried out through compilation and provision of a general summary of the findings of the research on completion of the study. Participants were informed that this would be made available on a publically accessible noticeboard in the Department of Psychology and that they were welcome to contact the researcher and/or research supervisor for further information and/or any queries.

5.6. Data analysis

After data collection for the pilot phase of the study was concluded, responses obtained from the 33 completed and returned *pilot study questionnaires* were captured electronically and analysed using a combination of frequency counts and aspects of conventional content analysis (Howell, 2013; Hsieh & Shannon, 2005). Frequency counts represent the number of times a category, event, or value of a variable under observation occurs within the data (Howell, 2013). Conventional content analysis is a technique used for summarising verbal data that consists of familiarisation, code derivation, categorisation (creation of meaningful clusters of codes), and interpretation of relationships or connections between the categories, typically leading to concept development or theoretical model building (Elo & Kyngäs, 2008; Hsieh & Shannon, 2005; Zhang & Wildemuth, 2009).

In addition, the data obtained from the 43 completed questionnaire packs that were returned was converted to numerical form and captured in *MS Excel*. This included the demographic characteristics of the pilot phase participants (these were either captured

directly or converted from categorical form) as well as the responses for both the *spontaneous analogical transfer task* and the *open analogical transfer task* (these were transcribed verbatim into *MS Word*, coded using a conventional content analysis approach (cf. Hsieh & Shannon, 2005; Zhang & Wildemuth, 2009), and scored). Although responses for both the *verbal analogical reasoning task* and the *self-reported heuristic strategy preference measure* were also captured, these were not analysed further due to the small sample size.

In order to describe the characteristics of the participants obtained for the pilot phase of the study, frequencies and percentages for the categorical variables assessed in the *demographic questionnaire* were calculated (Howell, 2013). These included: gender, race, faculty, year of study, number of spoken languages, home language, educational background, self-reported English proficiency, a range of socioeconomic factors, and socioeconomic status. In addition, means, standard deviations, and histograms for age and modal preference (treated as interval-scale and continuous variables) were calculated (Howell, 2013). The mean represents the average of the data obtained, standard deviation provides an indication of the extent to which the data is distributed or spread out around the mean (or an alternate measure of central tendency), and histograms provide a graphic representation of the data points that allows for interpretation of the shape and symmetry of the data (Howell, 2013). For the *spontaneous* and *open analogical transfer tasks*, frequencies for the overall number of solutions generated, the number of non-analogical, partial analogical, and analogical solutions generated, and each individual solution strategy proposed were calculated (Howell, 2013). This allowed for an assessment of the efficacy of the proposed tasks as well as an estimation of the likely rates of analogical transfer in the chosen target population and context.

For the main phase of the study, once data collection was complete the responses provided in the questionnaire packs were captured, converted to numerical form where necessary, and recorded in *MS Excel* using the coding frameworks developed in the pilot phase of the study. In order to establish the internal structures of the *verbal analogical reasoning task* and the *self-reported heuristic strategy preference measure* in the sample (specifically which, if any, items could be grouped together to form meaningful subscales), exploratory factor analyses in the form of principal component analyses were carried out (Fabrigar & Wegener, 2012; Fabrigar, Wegener, MacCallum, & Strahan, 1999; Stangor, 2015). Exploratory factor analysis consists of a set of multivariate statistical techniques that are "... designed to determine the number of distinct constructs needed to account for the pattern of correlations among a set of measures... [where] the researcher has no clear

expectations... about the underlying structure..." (Fabrigar & Wegener, 2012, pp.3-4).

Principal component analysis is a simple yet effective means of reducing the number of observed variables to a smaller set of independent composite variables whilst accounting for a maximum amount of variance (Fabrigar et al., 1999; Kline, 1994; Suhr, 2005). In addition, internal consistency reliability estimates (Cronbach Alpha coefficients) were calculated for these measures as well as the *Raven's Advanced Progressive Matrices* and the *modal preference* subscales, and item difficulties (p-values) were calculated for the *Raven's Advanced Progressive Matrices* and the *verbal analogical reasoning task* (Murphy & Davidshofer, 2005). Cronbach Alpha coefficients provide an estimate of the extent to which responses for individual items on a measure are consistent with one another based on average inter-item correlations; while item difficulty p-values represent the proportion of respondents who answer the item correctly in relation to the total number of people answering the item (Murphy & Davidshofer, 2005). Collectively these analyses were used to establish the psychometric properties of the measures employed in the study.

Frequencies and percentages were calculated for the categorical variables, and means, standard deviations, and histograms were calculated for the continuous and interval-scale variables assessed in the *demographic questionnaire* in order to describe the characteristics of the sample (Howell, 2013). Frequencies for the overall number of solutions generated, the number of non-analogical, partial analogical, and analogical solutions generated, and each individual solution strategy proposed were calculated for both the *directed* and the *open analogical transfer tasks* – the data yielded from these tasks was categorical in nature and represented analogical problem solving (Howell, 2013). In addition, means, standard deviations, ranges, skewness, kurtosis, and histograms were calculated for each of the other main variables of interest in the study that were continuous and treated-as-interval-scale in nature (verbal and non-verbal analogical reasoning and self-reported heuristic strategy preference for each item and subscale) (Howell, 2013). The range represents the minimum and maximum scores obtained for a particular variable, and skewness and kurtosis are both used to assess the degree of symmetry or asymmetry of the distribution of the data (Howell, 2013).

The histograms, skewness coefficients, kurtosis values, and overall size of the sample (based on Central Limit Theorem) suggested that the bulk of the continuous and treated-as-interval-scale data obtained was sufficiently normally distributed to meet the requirement for parametric testing (Howell, 2013; Norman, 2010). However the overall scores for the *verbal analogical reasoning task* and responses for one of the items in the *self-reported heuristic strategy preference measure* were heavily skewed. These scores

were not able to be normalised even with the application of standard transformation techniques thus appropriate non-parametric alternative analyses were applied in these cases (Howell, 2013; Norman, 2010). In addition, it is worth highlighting that two of the core variables within the study (directed analogical transfer and open analogical transfer) were categorical in nature – this severely limited the scope and sophistication of the statistical analyses that could potentially be applied to address the research questions (Howell, 2013; Norman, 2010).

In addition to describing the data obtained, the frequencies calculated for the overall number of solutions generated, the number of non-analogical, partial analogical, and analogical solutions generated, and each individual solution strategy proposed for both the *directed* and *open analogical transfer tasks* addressed the first two research questions posed in the study. These were to establish the rate of directed analogical transfer between a given source analogue and an isomorphic target problem based on the convergence schema, and the rate of open analogical transfer between two problem isomorphs without a pre-conceived solution strategy, respectively. In order to establish the nature of the relationship between the rates of directed and open analogical transfer within the same sample group (the third research question), a Chi-squared Test of Association was carried out. The Chi-squared Test of Association is a statistical technique that is used to establish if a significant association (relationship) exists between two variables that are both categorical in nature hence its appropriateness in this instance (Howell, 2013).

To establish the nature of the relationships between directed analogical transfer (three categories – fully analogical, partially analogical, and non-analogical), non-verbal and verbal analogical reasoning skill, and self-reported heuristic strategy preference (elements of the fourth and fifth research questions), a series of one-way ANOVAs (with post-hoc testing) and, where necessary, Kruskal-Wallis H tests were conducted (Howell, 2013). Although not originally conceptualised as part of the research questions, the relationships between directed analogical transfer and modal preference were also explored using one-way ANOVAs (with post-hoc testing). The one-way ANOVA (Analysis of Variance) is a parametric test of significance that is used to establish if there is a statistically significant difference between at least one pair of means for three or more different groups – this is typically followed by post-hoc testing which is carried out to identify which specific pairs of means differ statistically (Howell, 2013). The Kruskal-Wallis H test is a non-parametric technique that is considered ‘equivalent’ to the one-way ANOVA; it is used to assess if there are statistically significant differences between two or more groups based on ranks (Howell, 2013). The results of these techniques indicated whether there were statistically significant

differences in levels of verbal and non-verbal analogical reasoning skill, self-reported heuristic strategy preference, and modal preference on the basis of having presented a fully analogical, partially analogical, or non-analogical solution to the directed transfer task. In addition, scores for verbal and non-verbal analogical reasoning skill were converted to categorical form and the nature of the relationships between these and directed analogical transfer further assessed using Chi-squared Tests of Association. This was done to provide additional detail relevant to addressing the fourth research question posed, which was deemed a critical research question in the study.

To establish the nature of the relationships between open analogical transfer (two categories – analogical and non-analogical), non-verbal and verbal analogical reasoning skill, and self-reported heuristic strategy preference (elements of the fourth and fifth research questions), a series of two independent samples t-tests and, where necessary, Mann-Whitney U tests were conducted (Howell, 2013). Although not originally conceptualised as part of the research questions, the relationships between directed analogical transfer and modal preference were also explored using two independent samples t-tests. The two independent samples t-test is a parametric test of significance that is used to establish if there is a statistically significant difference between the means of two unrelated (independent) groups (Howell, 2013). The Mann-Whitney U test is a non-parametric technique that is considered 'equivalent' to the two independent samples t-test; it is used to establish if there is a statistically significant difference between two groups based on ranks (Howell, 2013). The results of these techniques indicated whether there were statistically significant differences in levels of verbal and non-verbal analogical reasoning skill, self-reported heuristic strategy preference, and modal preference on the basis of having presented an analogical or non-analogical solution to the open transfer task. In addition, scores for verbal and non-verbal analogical reasoning skill were converted to categorical form and the nature of the relationships between these and open analogical transfer further assessed using Chi-squared Tests of Association. This was done to provide additional detail relevant to addressing the fourth research question posed, which was deemed a critical research question in the study.

To address the sixth research question regarding the nature of the relationships between both directed and open analogical transfer and various demographic characteristics (gender, home language, type of schooling, and socioeconomic status), a series of Chi-squared Tests of Association were run as all of the variables involved were categorical in nature (Howell, 2013).

To address the seventh and final research question re the extent to which verbal and non-verbal analogical reasoning, self-reported heuristic strategy preference, gender, home language, type of schooling, and socioeconomic status were predictive of both directed and open analogical transfer (please refer to Section 4.15), a series of logistic regressions were run (Hosmer & Lemeshow, 2000; Huck, 2008). Logistic regression is an extension of traditional multiple regression, which is used to create a statistical model suitable for predicting a continuous outcome or criterion variable on the basis of two or more explanatory or predictor variables (Hosmer & Lemeshow, 2000; Howell, 2013). Logistic regression, however, allows for the prediction of a categorical outcome or criterion variable through probability estimation using a logistic function (Hosmer & Lemeshow, 2000; Howell, 2013; Huck, 2008). In this instance both binomial and multinomial logistic regression were used – the former when open transfer (two categories) was the criterion of interest and the latter when directed transfer (three categories) was the criterion of interest. As a necessary prerequisite step before carrying out the calculations for the logistic regressions, the nature of the relationships between each of the predictor variables was also assessed. This was done using a series of one-way ANOVAs, Kruskal-Wallis H tests, two independent samples t-tests, Mann-Whitney U tests, Chi-squared Tests of Association, Pearson's correlation coefficients, and Spearman's rank correlation coefficients as appropriate. Pearson's (product moment) correlation coefficients provide an estimation of the strength and direction of the relationship (association) between two continuous variables that are at least interval in nature (Howell, 2013). Spearman's rank correlation coefficients, which are considered as a suitable non-parametric 'equivalent' for Pearson's correlation coefficients, establish the statistical dependence between the ranks of two variables and can also be interpreted in terms of strength and direction of the association (Howell, 2013).

It is worth noting that effect sizes were calculated for all one-way ANOVAs, Kruskal-Wallis H tests, two independent samples t-tests, and Mann-Whitney U tests carried out during the analysis of the data. Effect size can be defined as “...a simple way of quantifying the difference between two groups that has many advantages over the use of tests of statistical significance alone. Effect size emphasises the size of the difference rather than confounding this with sample size...” (Coe, 2002, p.1). In essence, effect sizes give an indication of the practical significance of the results, although there is contestation regarding the interpretation of these estimates (Biddix, 2016; Lipsey et al., 2012).

All of the statistical analyses carried out in the study were run using the *IBM SPSS 23* statistical package; other analyses were carried out manually by the researcher.

5.7. Conclusion

This chapter has described the process followed to collect data for the study, including the overarching research design, the sample, the instruments, the procedure, ethical considerations, and an overview of how the data was analysed. The design of the study was quantitative, non-experimental, correlational, and cross-sectional. The final sample obtained consisted of six hundred and fifty-eight undergraduate students registered for first-year Psychology at the University of the Witwatersrand. Measures administered included a demographic questionnaire; tasks designed to assess directed analogical transfer, open analogical transfer, and verbal analogical reasoning; a standardised test of non-verbal analogical reasoning; and a self-developed measure of heuristic strategy preference. Administrative procedures were piloted and standardised as far as possible, and all relevant ethical considerations were adhered to. The data obtained was captured and analysed using a series of statistical procedures aligned to the research questions posed. The following chapter will present the results of the analyses that were carried out, as well as preliminary discussion of these in relation to the research questions they were used to address.

Chapter 6: Results

This chapter presents the results obtained for all of the analytic procedures carried out during both the pilot and main phases of the study. This includes a description of the findings obtained regarding the broader perceived feasibility of the study; the scoring and psychometric properties for the measures applied; and descriptive characteristics of the data obtained from the sample. It also includes discussion of the outcomes of the analyses implemented to address the core research questions posed. All of the statistical analyses carried out were run using the *IBM SPSS 23* statistical package; other analyses were carried out manually by the researcher.

6.1. Pilot phase: Pilot questionnaire

The pilot questionnaire was designed to elicit perceptions of the feasibility of the proposed procedure for the study and the appropriateness of the measures included in the questionnaire pack (excluding the *Raven's Advanced Progressive Matrices*) from the pilot study sample. A total of 33 questionnaires were completed and returned. The responses obtained were analysed using a combination of frequency counts and aspects of conventional content analysis (Howell, 2013; Hsieh & Shannon, 2005).

For total time taken to complete the questionnaire pack, 51% (19) of the respondents indicated that the time was fifty minutes or less, whilst 15% (5) indicated that the time was seventy minutes or more (please refer to Table G.1 in Appendix G). Although this was as anticipated, it did confirm the length of time demanded from participants as a potential area of concern (particularly when paired with the administration of the *Raven's Advanced Progressive Matrices* which brought the total time to approximately an hour-and-a-half to two hours on average). This concern was emphasised in certain of the responses given by the respondents regarding their perceptions of how willing other students would be to volunteer for the study. For this item, 22 (67%) of the respondents indicated that they did feel other students would be willing to volunteer, 8 (24%) indicated that they felt they would be both willing and unwilling, and 3 (9%) indicated that they felt other students would be unwilling. The primary themes that emerged from the open-ended explanations included: general interest and relevance for the chosen sample group; the importance of the incentives in promoting participation; and the length of time required and possible response biases that might emerge as a result of this. These themes are illustrated by the quoted responses provided below.

“It is interesting and challenging. Problem solving is an interesting topic too. Students will be intrigued...”

“Interesting study, can get valuable information about learning styles [incentive]; some questions take a bit of time to answer – may be a bit off-putting...”

“I think psych students might be interested in participating given their knowledge re the NB of the research. I am concerned that given the questionnaire’s length some participants might not take it seriously and be tempted to make up responses...”

“Only if there is an incentive as it is a long study; students love free stuff...”

As a direct result of the feedback from these items, the additional incentive of receiving course credit was incorporated during the main phase of the study. This proved to be a highly successful additional measure to boost participation, and a large sample ($n = 658$) was obtained despite the time considerations involved. The use of incentives, however, also raised concerns of potential response biases, including random responding, logical error in rating, and social desirability (Murphy & Davidshofer, 2005).

Another concern regarding the procedure involved respondents being permitted to complete the questionnaire in a non-controlled environment and potentially requesting assistance from others, thus interfering with the independence of the responses. A specific item regarding whether respondents had asked for help when completing the pack in their own time was thus incorporated into the pilot study questionnaire. The majority of the respondents (29 (88%)) indicated that they had not requested any assistance. Of the 4 (12%) respondents who had requested assistance, two queries were more factual in nature (level of highest education completed by a parent and the meaning of the word ‘ambivalence’), whereas two were linked directly to solving of the tasks (regarding question 25 in the *verbal analogical reasoning task* and the aquarium problem in the *spontaneous analogical transfer task*). Although this did not entirely negate the original concern, which remained a potential limitation of the study as a whole, it did suggest that a majority of the participants would be likely to adhere to the instructions given regarding independent completion of the questionnaire pack. It also highlighted that in the minority of cases where assistance was requested, certain of these requests would potentially not be problematic as regards independence of the responses.

The intention for participants to complete the questionnaire pack independently and in their own time also made it critical that the instructions provided were clear and understandable. This was found to be the case, as all of the respondents (33 (100%)) indicated that the instructions for each section were easy to follow. The respondents were

also asked to indicate whether they had any concerns regarding the nature of the questions, the language used, and appropriateness for the South African context for any of the core instruments included in the questionnaire pack (please refer to Table G.2 in Appendix G). A few relevant further concerns or points for consideration were raised under the open request for additional comments at the end of the questionnaire.

For the demographic questionnaire (including ranking of modal preference), 3 (9%) respondents raised concerns. These were: possible ambiguity (for type of schooling); the repetitiveness of the modal preference items; and non-consideration of language preference. For the reading comprehension component of the *spontaneous analogical transfer task*, 1 (3%) respondent raised a concern regarding the level of language. This concern was echoed in a general comment where a respondent (1 (3%)) indicated that as a second-language English speaker it would have been useful to have definitions for a few of the words used throughout the questionnaire pack. For the *transfer tasks* generally, 6 (18%) respondents raised concerns which focused entirely on the difficulty involved in generating creative solutions. One respondent (1 (3%)) also noted as an additional comment that as a whole these exercises were quite long and repetitive. For the *verbal analogical reasoning task*, 6 (18%) respondents raised concerns and one additional relevant issue (1 respondent (3%)) was raised under general comments. These concerns focused on the meaning and connotations associated with certain words used in the questions, as well as the general level of difficulty of the task. For the *heuristic strategy preference measure*, 4 (12%) respondents raised concerns and one additional issue was raised by a respondent (1 (3%)) under general comments. These related to interpretation of the scale anchors; confusion regarding the context specified; and a suggestion that preference would vary across individual circumstances. Lastly, 2 (6%) respondents included general comments suggesting the inclusion of additional space for answers and online administration.

In order to address the concerns raised regarding level of language, participants were verbally instructed during the main study that it would be acceptable for them to contact the researcher to ask the meaning of words if necessary. Participants were also verbally instructed that it might be useful to write out the options represented by the letters in the *heuristic strategy preference measure* once at the top of the questionnaire. Although important, the remainder of the concerns raised were not taken further due to the individual nature of the concern (most issues were raised only by a single individual) and/or other practical or technical considerations.

6.2. Pilot phase: Analogical transfer

For the pilot phase of the study, 43 questionnaires were completed and returned. The responses obtained for both the *spontaneous analogical transfer task* (the aquarium problem) and the *open analogical transfer task* (the thirsty-bird and ball-in-the-wall problems) (please refer to Appendix F) were transcribed verbatim into *MS Word*, coded by the researcher using a conventional content analysis approach (cf. Hsieh & Shannon, 2005), and scored based on systems developed by the researcher as part of the piloting process. A portion of the responses obtained were also coded independently by a second rater in order to provide an estimate of inter-rater reliability.

Table 6.1 provides an overview of the number of distinct solutions generated by all participants for each of the three problems presented as part of the *analogical transfer tasks*. On average, participants in the pilot study generated approximately four distinct solutions for the aquarium problem ($M = 4.26$; $S = 1.69$); approximately three distinct solutions for the thirsty-bird problem ($M = 2.63$; $S = 1.07$); and approximately three distinct solutions for the ball-in-the-wall problem ($M = 3.02$; $S = 1.34$).

Table 6.1

Pilot phase: Number of distinct solutions per participant for the analogical transfer tasks

No. solutions	Frequency (aquarium)	% (aquarium)	Frequency (bird)	% (bird)	Frequency (ball)	% (ball)
1	1	2.3	6	14.0	6	14.0
2	7	16.3	13	30.2	10	23.3
3	7	16.3	18	41.9	12	27.9
4	8	18.6	4	9.3	8	18.6
5	10	23.3	1	2.3	6	14.0
6	7	16.3	1	2.3	1	2.3
7	1	2.3	0	0.0	0	0.0
8	2	4.7	0	0.0	0	0.0
Total	43	100	43	100	43	100
Average	4.26		2.63		3.02	
Std. Dev.	1.692		1.070		1.336	

6.2.1. Spontaneous analogical transfer.

Initial coding of the distinct solutions provided for the aquarium problem (which represented spontaneous analogical transfer in the pilot study) by the researcher yielded twenty-nine separate solution strategies, each represented by a mutually exclusive and

exhaustive category (Hsieh & Shannon, 2005; Zhang & Wildemuth, 2009). In other words, each distinct solution could only be represented once within a particular solution category and all distinct solutions were coded. Categories were based on unique types of solutions proposed and were named in accordance with these. Six of these categories (alternate light sources; different positioning; reduced intensity; multiple lights; circular disposition (situation of lights in a circle around the ship); and simultaneous summation (combined application of the lights)) represented aspects of the convergence solution; the remainder represented alternate solutions that were not deemed analogical in nature (please refer to Table G.3 in Appendix G for a full list of categories and acronyms).

Secondary coding of a portion of the solutions was then carried out by an independent analyst (a suitably qualified graduate with experience in data analysis) in order to verify the initial coding and provide an estimate of inter-rater reliability. The analyst was provided with a list of the categories generated during the initial coding as well as a sample of twenty raw responses, and was asked to re-code the data contained therein (including generating additional or alternate categories if this was felt to be necessary). Initial coding of the sample of responses resulted in the identification of ninety-five distinct solutions; for the secondary coding, ninety-four distinct solutions were identified. There were no category differences between the two coders, however nine of the distinct solution codes differed representing a rate of agreement of approximately 91.4%. The primary area of disagreement between the two coders related to the coding of one specific solution – the suggestion that individual observers should each be given a torch or individual head light. In the initial coding, this was recorded as representing reduced intensity and a different light source; whereas in the secondary coding, this was recorded as representing multiple lights and implied circular disposition. To resolve this conflict, an additional category was added to the list representing the specific solution scenario, bringing the total number of possible categories to thirty. It was agreed that this category would be regarded as representing both the idea of reduced intensity and the idea of multiple lights, but not implied circular disposition unless additional information was specified in the answer given. Aside from this, the only other discrepancy related to two suggestions of using glow-sticks, which the first coder recorded as both a different light source and use of fluorescence and the second coder recorded as only a different light source. It was agreed that both codes would be used for this solution type for coding of the rest of the data.

Following this process, coding of the distinct solutions for the aquarium problem for the pilot phase of the study was finalised – the frequencies for these are presented in Table 6.2.

Table 6.2

Pilot phase: Solution category frequencies for the spontaneous analogical transfer task (n = 43)

Solution category	n	%	Solution category	n	%
ANS1RI	25	58.1	ANS1DLS	14	32.6
ANS2ML	17	39.5	ANS1DP	15	34.9
ANS3CD	4	9.3	ANS2TRC	6	14.0
ANS4SS	4	9.3			
NADPT	6	14.0	NPNTTL	4	9.3
NADPTP	2	4.7	NPOST	3	7.0
NADJT	1	2.3	NREFL	4	9.3
NARTF	3	7.0	NREMV	3	7.0
NBARR	5	11.6	NROOM	3	7.0
NFLOR	14	32.6	NROOML	3	7.0
NGOGG	3	7.0	NSENS	4	9.3
NGOGGS	3	7.0	NSNRF	4	9.3
NLCVR	3	7.0	NTINT	2	4.7
NLITK	1	2.3	NTMPC	9	20.9
NLRGE	5	11.6	NVISH	11	25.6
NPICT	2	4.7			

A = analogical; N = non-analogical; ANS1RI = reduced intensity; ANS1DLS = different light types; ANS1DP = different light positions; ANS2ML = multiple lights; ANS2TRC = independent lights/torches; ANS3CD = circular disposition; ANS4SS = simultaneous summation; NADPT = genetic adaptation; NADPTP = adaptation process; NADJT = adjustable lighting; NARTF = artificial stock; NBARR = barriers in tank; NFLOR = fluorescence; NGOGG = night vision goggles; NGOGGS = camera system; NLCVR = light covering; NLITK = light inside tank; NLRGE = larger replica; NPICT = pictures/ models; NPNTTL = paint room light; NPOST = change replica positioning; NREFL = reflective surfaces; NREMV = remove fish; NROOM = dark room; NROOML = well-lit room; NSENS = controlled lighting; NSNRF = skylight/sunroof; NTINT = tinted windows; NTMPC = temperature control; NVISH = visiting hours

A scoring system to represent degree of analogical problem solving was then developed based on these categories. Seven of the categories were identified as representing aspects of the convergence solution and thus as representative of partial or complete analogical problem solving (cf. Antonietti & Gioletta, 1995; please refer to Chapter 5 for additional detail). Using a different light source, changing the position of the light, and reducing the intensity or strength of the light were scored as 1, representing the first of the four features identified by Antonietti and Gioletta (1995) – ‘reduced intensity’. Both the use of multiple lights and the use of a torch or head light for each participant were scored as 2, representing the second feature identified by Antonietti and Gioletta (1995) – ‘multiple lights’.

The last two features identified by Antonietti and Gioletta (1995) – ‘circular disposition’ and ‘simultaneous summation/application’ were equated directly with the two categories developed to represent these concepts and were scored as 3 if one of the two features was present and as 4 if both features were present (provided the first two features were present as well). A breakdown of the scores obtained in the pilot sample based on this categorisation is given in Table 6.3. On the basis of these scores, participants were then classified as having produced a non-analogical solution (no features); a partial analogical solution (a score of 1 or 2 representing the notions of reduced intensity and multiple lights), or a full analogical solution (a score of 3 or 4 representing a full analogical solution). The breakdown for this classification is also provided in Table 6.3.

Table 6.3

Pilot phase: Convergence category scores and classification for the spontaneous analogical transfer task (n = 43)

Category		n	%
Convergence category scores	0 (none)	15	34.9
	1 (reduced intensity)	10	23.3
	2 (multiple lights)	11	25.6
	3 (circular disposition)	6	14.0
	4 (simultaneous application)	1	2.3
Classification	0 (non-analogical)	15	34.9
	1 (partial analogical)	21	48.8
	2 (full analogical)	7	16.3

Although not unexpected, the number of full analogical solutions generated by the pilot sample was very low (approximately 16% (7)). This suggested that if the task were maintained as a spontaneous task for the main phase of the study, the rates of analogical problem solving obtained could have been too low to permit analysis of the main research questions posed. As a result, and despite certain limitations created by the change, it was decided to adapt the task to one representing directed transfer for the main phase of the study. This was done by adding a general hint regarding the potential relevance of the comprehension exercise at the end of the instructions (please refer to Appendix F).

6.2.2. Open analogical transfer.

Solutions provided for the thirsty-bird and ball-in-the-wall problems (Chen & Daehler, 1989; please refer to Appendix F) were coded separately prior to retrospective analysis of

shared structural similarity between the solution strategies given – these were then used as a basis for evidence of open analogical transfer having occurred (please refer to Chapter 5 for additional detail). Initial coding of the solutions by the researcher yielded eighteen and fourteen categories (distinct solutions) respectively – each of these were mutually exclusive and exhaustive (Hsieh & Shannon, 2005; Zhang & Wildemuth, 2009) (please refer to Table G.4 and Table G.5 in Appendix G for a full list of categories and acronyms).

Secondary coding of a portion of the solutions (twenty raw responses for each problem) was then carried out by an independent analyst. As for the *spontaneous transfer task*, the analyst was provided with a list of the categories generated during the initial coding and was asked to re-code the data (including generating additional or alternate categories if this was felt to be necessary). It is worth noting that the independent analyst initially expressed concerns regarding the level of fine detail used to distinguish between certain of the categories generated during the initial coding. This, however, was felt to be necessary by the researcher given the retrospective nature of the scoring and the potential difficulty in identifying structural equivalence. Following completion of the re-coding, the independent analyst withdrew these concerns and indicated that nuances in the responses allowed for distinct categorisation of these to occur fairly easily despite superficial similarities between descriptions of certain of the categories.

Initial coding of the sample of responses for the thirsty-bird problem resulted in the identification of fifty-eight distinct solutions; this was also the number of distinct solutions identified by the independent analyst. There were no category differences between the two coders, and only three distinct solution codes differed representing a rate of agreement of approximately 94.8%. The differences occurred as a result of one solution being categorised as breaking the bottle by the independent coder instead of as breaking open the top of the bottle thereby changing the shape; and two solutions being categorised by the independent coder as placing the bottle horizontally (thereby changing the angle of accessibility) instead of as knocking the bottle over allowing water to spill on the floor. A review of the wording of these two solutions suggested that they were insufficiently specific to accommodate the level of distinction required by the two codes. It was therefore agreed that all responses of this nature would be classified as knocking the bottle over unless spillage of water was specified, thus ensuring consistency despite the inherent ambiguity. Both the initial and secondary coding for the sample of responses for the ball-in-the-wall problem yielded sixty-seven distinct solutions. The rate of agreement between the two coders for these was 100%.

Following completion of the secondary analysis, coding of the distinct solutions for the two problems for the pilot phase of the study was finalised – the frequencies for these are presented in Table 6.4.

Table 6.4

Pilot phase: Solution category frequencies for the open analogical transfer task (n = 43)

Solution category	n (Bird)	% (Bird)	Solution category	n (Ball)	% (Ball)
XALTW	8	18.6	YBYNB	11	25.6
XANGL	6	14.0	YCHWG	32	74.4
XBRKB	1	2.3	YCRTE	1	2.3
XCTCH	12	27.9	YFRCE	5	11.6
XDEWR	3	7.0	YGLVE	2	4.7
XDIPP	2	4.7	YGVUP	1	2.3
XEATS	12	27.9	YHELP	12	27.9
XHELP	2	4.7	YINVN	7	16.3
XHOLE	10	23.3	YLBRC	1	2.3
XHRZN	11	25.6	YNLRG	10	23.3
XINCL	14	32.6	YPLQD	26	60.5
XKOVR	13	30.2	YRSCH	1	2.3
XPEBB	7	16.3	YSCTN	2	4.7
XREST	2	4.7	YTOOL	19	44.2
XROLL	5	11.6			
XSHPB	1	2.3			
XSTPR	1	2.3			
XSTRW	3	7.0			

X = thirsty bird; Y = ball-in-the-wall; XALTW = alternate water source; XANGL = angle/ tilt bottle; XBRKB = break bottle; XCTCH = catchment device; XDEWR = dew/ rain; XDIPP = use dipper; XEATS = eat other; XHELP = get help; XHOLE = make a hole; XHRZN = place horizontally; XINCL = create incline; XKOVR = knock bottle over; XPEBB = pebble displacement; XREST = rest; XROLL = roll/ shake bottle; XSHPB = change bottle shape; XSTPR = use stopper; XSTRW = create a straw; YBYNB = buy new ball; YCHWG = chewing gum and pole; YCRTE = create a new ball; YFRCE = exert force/ pressure; YGLVE = use gloves; YGVUP = give up; YHELP = get help; YINVN = invent a tool; YLBRC = lubricate the ball; YNLRG = enlarge the hole ; YPLQD = pour liquid; YRSCH = do research; YSCTN = create suction; YTOOL = use a tool

A detailed review of each category for both problems was then conducted in order to identify the extent to which the implied solution strategy could be considered structurally similar to one or more solutions presented for the other problem. Four distinct sets of strategies were deemed to be structurally similar and thus retrospectively representative of open analogical transfer having occurred. One of these strategies – *displacement* (represented by the use of pebbles for the thirsty-bird problem and the use of liquid for the

ball-in-the-wall problem to cause the desired object to rise) was directly equivalent to the analogical solution set identified by Chen and Daehler (1989) for the two problems. The other strategies identified were *extraction* (dipping an object into the bottle and extracting water, and using chewing gum at the end of an object to extract the ball); *suction* (using an object as a ‘straw’ thus creating sufficient pressure to extract the desired object for both problems); and *modification* (breaking the bottle, changing the shape of the bottle, or creating a hole in the bottle, all three of which were deemed to be analogous to enlarging the hole in the wall). The number of participants who identified each analogous strategy set as well as the total number of analogous sets identified is given in Table 6.5. Participants who presented one or more of these sets were then scored as having presented evidence of open analogical transfer; whilst those participants who did not present any of the sets across the two problems were scored as having presented non-analogous solutions. Frequencies for this classification in the pilot sample are also given in Table 6.5.

Table 6.5

Pilot phase: Analogical solution frequencies and classification for the open analogical transfer task (n = 43)

Category		n	%
Number of pairs	None	33	76.7
	One pair	9	20.9
	Two pairs	1	2.3
Pair 1	Displacement	6	14.0
Pair 2	Extraction	2	4.7
Pair 3	Suction	0	0.0
Pair 4	Modification	3	7.0
Classification	0 (non-analogical)	33	76.7
	1 (analogical)	10	23.3

Although the direct association was not analysed, the rate of open analogical problem solving identified in the pilot sample (23% (10)) was similar to the rate of spontaneous analogical problem solving identified (16% (7)). This provided a small yet important degree of support for one of the key intended aims of the study as a whole, namely to develop an alternate yet valid method of evaluating analogical transfer whilst addressing certain of the concerns raised regarding the traditional procedure (cf. Day & Goldstone, 2012; Holyoak, 2012; Lave, 1988; Lobato, 2006; Nokes, 2009; Novick & Holyoak,

1991). Despite this, the retrospective nature of the identification process and assumptions inherent therein remained as a potential limitation of the study as a whole.

6.3. Pilot phase: Conclusion

Feedback from the participants in the pilot phase of the study suggested that the instructions provided for all of the measures and tasks in the questionnaire pack were clear and understandable; and relatively few concerns were raised regarding the nature of the questions, level of language used, or suitability for the South African context. In addition, a large majority of the participants (eighty-eight percent) indicated that they had fully adhered to the instruction to complete the questionnaire pack independently. As anticipated, the time required to complete the questionnaire pack was flagged as a potential issue by participants; however they also noted that this was balanced to an extent by the compensation offered and general interest. In order to further address this concern, an additional incentive in the form of course credit was offered to participants in the main phase of the study. Additional instructions for vocabulary queries and a tip for completing the *self-reported heuristic strategy preference measure* were also provided to participants in the main phase of the study to address certain of the technical concerns raised.

Responses obtained to the various measures and tasks in the pilot phase of the study supported their appropriateness for assessing the constructs of interest, with one notable exception – the *spontaneous analogical transfer task*. Only seven respondents (representing approximately seven percent of the pilot sample) provided ‘full’ analogical solutions for this task, raising serious concerns as to whether the proposed study would be viable if similar rates of transfer were obtained in the main study. As a result, and despite certain disadvantages, it was deemed necessary to provide participants with an additional overt hint regarding the relevance of the comprehension exercise as a source when considering solutions for the target analogue of lighting the aquarium (cf. Anolli et al., 2001; Hostetter et al., 2018). This altered the nature of the construct that was captured by the task, which became a measure of *directed analogical transfer* for the main study. Other than this change, the various tasks and measures, including the coding and scoring systems developed for the data obtained, were deemed suitable to utilise in the main phase of the study.

6.4. Main phase: Preliminary analyses

After completion of the pilot phase of the study, data for the main phase was collected, captured, and analysed. Prior to addressing the core research questions, it was necessary to establish the psychometric properties of the measures used to assess verbal and non-verbal

analogical reasoning, self-reported heuristic strategy preference, and modal preference; as well as basic descriptive statistics representing the data obtained in the sample.

6.4.1. Internal structure of the verbal analogical reasoning task.

In order to assess the internal consistency reliability of the thirty-two four-term analogies included in the *verbal analogical reasoning task* within the sample, an overall Cronbach Alpha estimate was calculated. This yielded an estimate of $\alpha = .56$, indicating very low internal consistency reliability (Murphy & Davidshofer, 2005). In order to improve this, a number of the items that were identified as reducing the internal consistency of the measure were removed, and the estimate re-calculated (please refer to Table H.1 in Appendix H). This resulted in a final pool of twenty-one items with a Cronbach Alpha estimate of $\alpha = .62$, representing a low level of internal consistency (Murphy & Davidshofer, 2005).

Cronbach Alpha estimates are affected by a range of factors, including the number of items, item inter-correlations, dimensionality, and response bias (Murphy & Davidshofer, 2005; Schmitt, 1996; Vaske et al., 2016). The dimensionality of the revised measure consisting of twenty-one items was thus assessed using exploratory factor analysis in the form of principal component analysis in order to identify whether this was a relevant consideration as well as to establish construct validity for the measure (Kline, 1994; Murphy & Davidshofer, 2005; Suhr, 2005).

The Kaiser-Meyer-Olkin Measure of Sampling Adequacy was 0.74 (above the suggested minimum cut-off of 0.6) and the null hypothesis for Bartlett's Test of Sphericity was rejected ($\chi^2_{210} = 721.21$; $p = .000$), thus meeting the minimum requirements for the analysis to be carried out.

In order to identify the number of factors to retain, four criteria were considered: the Eigenvalues; the scree plot; the results of the parallel analysis; and the results of the minimum average partial (MAP) test (Courtney, 2013). As shown in Table 6.6, Eigenvalues for the first eight factors were greater than one (thus meeting Kaiser's (1960) 'Eigenvalues-greater-than-one (K1)' criterion) (Courtney, 2013). In contrast, the results of the parallel analysis (also shown in Table 6.6), the MAP technique, and the scree plot (shown in Figure 6.1) all strongly supported the extraction of a single factor.

Table 6.6

Main phase: Eigenvalues for the revised verbal analogical reasoning task

Component	Eigenvalue	% Variance	Cumulative %	PA Percentile
1 (2)	2.693	12.822	12.822	1.371
2 (3)	1.266	6.026	18.848	1.300
3 (4)	1.229	5.851	24.699	1.258
4 (5)	1.220	5.809	30.508	1.214
5 (6)	1.127	5.365	35.873	1.178
6 (8)	1.070	5.096	40.969	1.145
7 (10)	1.036	4.934	45.903	1.115
8 (12)	1.034	4.922	50.825	1.081
9 (14)	0.984	4.688	55.513	1.058
10 (16)	0.943	4.492	60.004	1.028
11 (18)	0.880	4.190	64.195	1.005
12 (19)	0.859	4.090	68.285	0.982
13 (20)	0.853	4.064	72.349	0.951
14 (22)	0.828	3.942	76.291	0.924
15 (23)	0.810	3.858	80.149	0.907
16 (24)	0.761	3.625	83.774	0.880
17 (26)	0.728	3.465	87.239	0.856
18 (28)	0.703	3.350	90.589	0.830
19 (29)	0.687	3.270	93.858	0.798
20 (30)	0.659	3.140	96.998	0.772
21 (31)	0.630	3.002	100.00	0.731

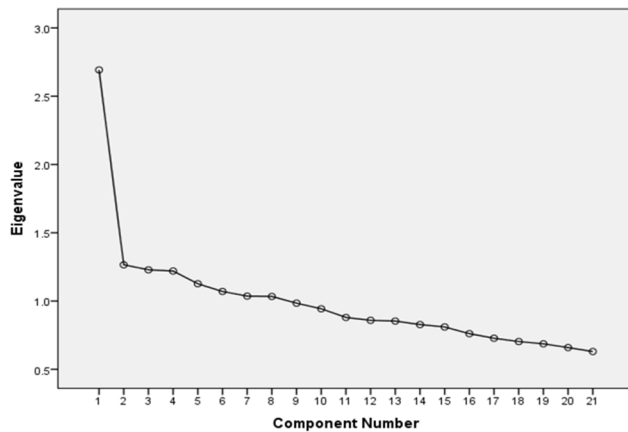


Figure 6.1. Scree plot for the revised verbal analogical reasoning task.

A number of theorists (cf. Courtney, 2013; Fabrigar et al., 1999; Hayton, Allen, & Scarpello, 2004; Ledesma & Valero-Mora, 2007; O'Connor, 2000) have suggested that the K1 criterion is somewhat arbitrary and tends to over-factor, and that the scree plot is difficult to interpret objectively; they have thus proposed weighting the findings from the parallel analysis and MAP procedure more heavily when identifying a final number of factors for extraction. In addition, the groupings of items identified as loading on each of the eight rotated factors based on an orthogonal varimax rotation (Fabrigar et al., 1999) lacked both theoretical coherence and internal consistency (please refer to Table H.2 in Appendix H). Given these considerations, it was decided that it would be more appropriate to treat the twenty-one remaining items in the scale as unidimensional. Verbal analogical reasoning within the study was thus represented by a single score based on performance across the twenty-one items. It is important to note, however, that the internal consistency estimate for this grouping of items was low ($\alpha = .62$), possibly as a result of aspects of dimensionality implied in the principal component analysis or potentially due to other factors such as response bias, and this became a limitation of the study as a whole.

6.4.2. Internal structure of the self-reported heuristic strategy preference measure.

In order to assess the internal consistency reliability of the twenty items included in the *self-reported heuristic strategy preference measure* within the sample, an overall Cronbach Alpha estimate was calculated. This yielded an estimate of $\alpha = .75$, indicating moderate-to-high internal consistency reliability (Murphy & Davidshofer, 2005).

In order to establish construct validity for the measure, as well as to identify whether the distinct problem-solving methods or behaviours represented by the individual items could be grouped into the five broader strategy clusters distinguished by Antonietti et al. (2000), exploratory factor analysis in the form of principal component analysis was carried out. As for the *verbal analogical reasoning task*, the criteria used to identify the number of factors to retain were the Eigenvalues; the scree plot; the results of the parallel analysis; and the results of the minimum average partial (MAP) test (Courtney, 2013; Kline, 1994; Suhr, 2005). Given the potentially inter-related nature of the items, an oblique promax rotation was applied (Fabrigar et al., 1999).

The Kaiser-Meyer-Olkin Measure of Sampling Adequacy was 0.76 and the null hypothesis for Bartlett's Test of Sphericity was rejected ($\chi^2_{190} = 2005.03$; $p = .000$), thus meeting the minimum requirements for the analysis to be carried out.

As shown in Table 6.7, Eigenvalues for the first six factors were greater than one (Courtney, 2013). The results of the parallel analysis (also shown in Table 6.7), and the scree plot (shown in Figure 6.2) supported the extraction of four factors. The MAP technique, which can sometimes under-factor, supported the extraction of a single factor; this was to some extent aligned with the scree plot where a single factor was placed sharply above the others on the slope (O'Connor, 2000). Taken together, the criteria suggested that the items, whilst inter-related, could be separated into four meaningful subscales subsumed under a broader single construct represented by the test as a whole. It is important to note that although the intended alignment with Antonietti et al.'s (2000) strategy clusters was thus not achieved, Antonietti et al. (2000) developed the grouping of their strategies theoretically and did not conduct formal empirical testing to support these.

Table 6.7

Main phase: Eigenvalues for the self-reported heuristic strategy measure

Component	Eigenvalue	% Variance	Cumulative %	PA Percentile
1	3.817	19.083	19.083	1.397
2	1.858	9.291	28.374	1.327
3	1.463	7.314	35.688	1.270
4	1.367	6.834	42.522	1.226
5	1.103	5.515	48.037	1.188
6	1.033	5.164	53.202	1.151
7	0.995	4.977	58.179	1.117
8	0.928	4.639	62.818	1.087
9	0.900	4.500	67.318	1.057
10	0.827	4.136	71.454	1.027
11	0.795	3.974	75.428	0.999
12	0.713	3.563	78.991	0.971
13	0.673	3.366	82.357	0.944
14	0.627	3.133	85.490	0.918
15	0.592	2.958	88.448	0.891
16	0.555	2.774	91.222	0.865
17	0.515	2.577	93.799	0.836
18	0.484	2.422	96.221	0.807
19	0.407	2.036	98.257	0.775
20	0.349	1.743	100.00	0.738

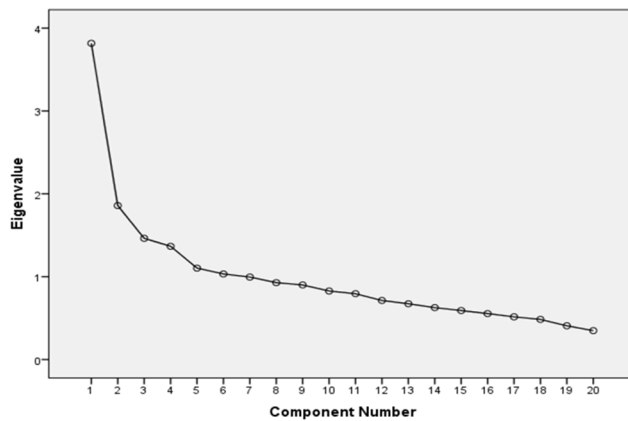


Figure 6.2. Scree plot for the self-reported heuristic strategy measure.

In order to identify which items loaded onto which subscales, an oblique promax rotation was carried out (Fabrigar et al., 1999). Items with a factor loading of .4 or higher were considered as contributing to that factor, and where items cross-loaded, only the highest factor loading was taken into account (Kline, 1994). As shown in Table 6.8, the first factor consisted of items drawn from the *step-by-step* and *visualisation* clusters (Items 3, 4, 8, 13, and 14); the second factor consisted of items drawn from the *free production* and *combining* clusters (Items 1, 5, 6, 10, 11, and 15); the third factor consisted of three items representing a preference for *analogy* (Items 2, 7, and 12); and the fourth factor consisted of *practical* strategies ranging across the clusters (Items 16, 17, 18, 19, and 20).

The primary focus for the *self-reported heuristic strategy preference scale* within the current study was to create a suitable means for identifying *analogy* as a preferred heuristic strategy. In this regard, the measure was successful as extraction of a meaningful *analogy preference* subscale of three items with a moderate-to-high internal consistency reliability ($\alpha = .76$) was achieved (Murphy & Davidshofer, 2005). Although the internal consistencies for the *step-by-step/visualisation* and *free production/combining* subscales were low ($\alpha = .63$ and $\alpha = .64$ respectively), these were nevertheless felt to represent useful alternate approaches to problem-solving and both were thus maintained in the study as well. The *practical* subscale, however, was not viable due to the extremely low internal consistency ($\alpha = .47$) and was thus discarded. However a decision was taken to explore the relevance of each individual item included in the scale (as representative of a unique problem-solving heuristic behaviour or approach) at certain points in the remainder of the analysis. A major recommendation of the current study remains the continued development and refinement of a suitable instrument for assessing heuristic strategy preference and application broadly.

Table 6.8

Main phase: Rotated factor pattern for the self-reported heuristic strategy measure

		Fact. 1	Fact. 2	Fact. 3	Fact. 4
Item 1	Brainstorm as many solutions as possible	.409	.460	.251	.069
Item 2	Recall past problems similar to current one	.284	.175	.799	.061
Item 3	Identify sequences/ phases/ steps	.579	.275	.444	.169
Item 4	Represent problem differently e.g. graph	.415	.332	.103	-.095
Item 5	Associate different elements/ unusual links	.175	.610	.211	.004
Item 6	Think creatively/ freely – many solutions	-.086	.742	.021	.193
Item 7	Previous situations – transfer shared features	.162	.185	.802	.037
Item 8	Break into sub-problems – solve each	.651	.078	.293	.091
Item 9	Imagine best way to solve problem	.336	.256	.118	.305
Item 10	Combine different aspects – creative solution	.351	.662	.154	.160
Item 11	Many ideas – then analyse and choose best	.204	.433	.109	.273
Item 12	Principles used for previous similar problems	.367	.118	.800	.067
Item 13	Systematically plan and order steps	.771	.143	.289	.128
Item 14	Restructure/ re-formulate into easier format	.608	.249	.020	.029
Item 15	New combinations from existing knowledge	.409	.549	.188	.155
Item 16	Do something else until solution ‘pops’	-.181	.209	-.230	.611
Item 17	Rule out aspects seemingly not relevant	.046	.108	.069	.585
Item 18	Think of idea and test it	.202	.112	.242	.503
Item 19	Think of what someone else would do	.080	.202	.081	.574
Item 20	Try to get help from others	.140	-.045	-.010	.478

6.4.3. Additional psychometric properties for the core measures

Table 6.9 presents Cronbach Alpha estimates representing internal consistency reliability for all of the core measures used in the study. Estimates for the *Raven's Advanced Progressive Matrices* (which represented non-verbal analogical reasoning) as well as the *modal preference listening* and *iconic* subscales were above .8, representing high internal consistency (Murphy & Davidshofer, 2005). As discussed earlier, the estimate for the *analogy preference* subscale was $\alpha = .76$, representing moderate-to-high internal consistency (Murphy & Davidshofer, 2005). Estimates for the *modal preference direct experience* and *modal preference listening* subscales were moderate and low-to-moderate respectively (Murphy & Davidshofer, 2005). As discussed earlier, estimates for the *revised verbal analogical reasoning task*, *step-by-step/visualisation preference* subscale, and *free production/combining preference* subscale were low.

Table 6.9

Main phase: Internal consistency reliabilities for the core measures (n = 658)

Variable	n	No. items	Cronbach α
RAPM (non-verbal analogical reasoning)	611	36	.832
RVRT-21 (verbal analogical reasoning)	599	21	.624
HSP Step-by-step/visualisation	628	5	.629
HSP Free production/combining	622	6	.644
HSP Analogy	641	3	.762
MP Listening	646	6	.682
MP Reading	647	6	.820
MP Iconic	648	6	.804
MP Direct experience	648	6	.738

Although it is widely agreed that Cronbach Alpha estimates below .7 are questionable (cf. Murphy & Davidshofer, 2005; Nunnally, 1978; Schmitt, 1996), there have been some theorists who have proposed that .6 as a cut-off is still adequate under certain circumstances (cf. Aron & Aron, 1999; Field, 2009; Hair, Black, Babin, Anderson, & Tatham, 2006). These include measures developed for research situations that are preliminary or exploratory in nature as well as cases in which the measure is felt to provide meaningful coverage of the construct/s being assessed (cf. Hair et al., 2006; Nunnally, 1978; Schmitt, 1996). Given that both these situations applied to the current study, a decision was taken to utilise those measures with low and low-to-moderate internal consistency reliability; although this was noted and remains a limitation of the study as a whole.

Item difficulties for both the *Raven's Advanced Progressive Matrices* and the *revised verbal analogical reasoning task* were also calculated (please refer to Table H.3 and Table H.4 in Appendix H) as these measures were performance-based in nature (Murphy & Davidshofer, 2005). Items in the *Raven's Advanced Progressive Matrices* are deliberately arranged to follow an ascending order of difficulty that has been shown to be valid across multiple contexts (cf. Bors & Stokes, 1998; Carpenter et al., 1990; Israel, 2006; Paul, 1985; Raven et al., 1998). The pattern of p-values (representing the proportion of individuals who answered the item correctly) for the *Raven's Advanced Progressive Matrices* scores in this study aligned with this anticipated pattern and ranged from very high (above .9) to very low (below .1) across the items (Murphy & Davidshofer, 2005). Estimates for the twenty-one items in the *revised verbal analogical reasoning task* were generally high (only six of the

items had p-values below .8). This suggested that the items may have failed to sufficiently distinguish levels of performance for verbal analogical reasoning and that the test may thus have exhibited ceiling effects within the sample (Murphy & Davidshofer, 2005). The resultant lack of variation could also at least partially account for the low Cronbach Alpha obtained (cf. Murphy & Davidshofer, 2005; Vaske et al., 2016).

6.5. Main phase: Descriptive statistics

Table 6.10 presents the means, standard deviations, ranges, skewness coefficients, and kurtosis estimates for all of the core continuous variables measured in the study that were treated as interval-scale in nature (Howell, 2013). These statistics were also calculated for each item included in the *self-reported heuristic strategy preference measure* (please refer to Table H.5 in Appendix H). Histograms for each of the core continuous variables were also generated (please refer to Figure H.1, Figure H.2, and Figure H.3 in Appendix H).

Table 6.10

Main phase: Descriptive statistics for the core continuous variables

Variable	n	Missing	Mean	Std. Dev.	Min.	Max.	Skewness	Kurtosis
RAPM	658	0	19.83	5.907	0	34	-0.426	0.368
RVRT-21	658	0	16.61	2.781	0	21	-1.394	4.024
HSP ST/V	649	9	17.26	3.651	6	25	-0.337	-0.228
HSP FP/C	649	9	20.35	4.040	6	30	-0.303	0.159
HSP ANL	649	9	11.07	2.510	3	15	-0.526	0.117
MP L	658	0	15.76	4.027	0	24	-0.380	0.711
MP R	658	0	13.05	4.960	0	24	0.208	-0.726
MP I	658	0	16.31	4.676	0	24	-0.481	-0.112
MP DE	658	0	14.92	4.615	0	24	-0.071	-0.290

RAPM = Raven's Advanced Progressive Matrices (non-verbal analogical reasoning); RVRT-21 = Revised Verbal Analogical Reasoning Task (verbal analogical reasoning); HSP ST/V = step-by-step/visualisation heuristic strategy preference; HSP FP/C = free production/combining heuristic strategy preference; HSP ANL = analogy heuristic strategy preference; MP L = listening modal preference; MP R = reading modal preference; MP I = iconic modal preference; MP DE = direct experience modal preference

The large sample size obtained suggested that normal distribution of the data could be assumed based on the Central Limit Theorem (Howell, 2013). As shown in Table 6.10, the majority of the skewness coefficients also fell within the range of one to minus one, with the exception of verbal analogical reasoning. Similarly, all of the kurtosis values fell within the range of three to minus three, with the exception of verbal analogical reasoning (Howell, 2013). Although a degree of skewing was suggested in certain of the histograms, only the

graph for the revised verbal analogical reasoning scores appeared heavily skewed (please refer to Figure H.3 in Appendix H).

Table 6.11

Main phase: Descriptive statistics for the core categorical variables

Variable	Categories	n	%
Directed analogical transfer (directed APS)	0 (non-analogical)	190	28.9
	1 (partial analogical)	229	34.8
	2 (full analogical)	189	28.7
	Missing	50	7.6
Open analogical transfer (open APS)	0 (non-analogical)	398	60.5
	1 (analogical)	194	29.5
	Missing	66	10.0
Gender	1 (male)	171	26.0
	2 (female)	487	74.0
Home language	1 (English)	378	57.4
	2 (other languages)	279	42.4
	Missing	1	0.2
Type of schooling	1 (government)	343	52.1
	2 (private)	292	44.4
	Missing	23	3.5
Socioeconomic status	1 (low)	226	34.3
	2 (average)	209	31.8
	3 (high)	222	33.7
	Missing	1	0.2
RVRT-2 (categorical)	1 (low)	367	55.8
	2 (high)	291	44.2
RAPM-2 (categorical)	1 (low)	351	53.3
	2 (high)	307	46.7

RVRT-2 = Dichotomous categorisation for the Revised Verbal Analogical Reasoning Task (verbal analogical reasoning); RAPM-2 = Dichotomous categorisation for the Raven's Advanced Progressive Matrices (non-verbal analogical reasoning)

This suggested that the bulk of the continuous and treated-as-interval-scale data obtained was sufficiently normally distributed to meet the requirement for parametric testing (Howell, 2013; Norman, 2010). However the overall scores for the *revised verbal analogical reasoning task*, as well as responses for Item 9 in the *self-reported heuristic strategy preference measure* (please refer to Table H.5. in Appendix H) were heavily skewed.

Attempts to transform this data using standard transformation techniques were unsuccessful thus appropriate non-parametric alternative analyses and/or transformations were used for analyses involving these variables (Howell, 2013; Norman, 2010).

Frequencies and percentages for all of the key categorical variables in the main study are presented in Table 6.11 (please refer to Section 6.2 for additional detail). This includes frequencies and percentages for directed and open analogical transfer, gender, home language, type of schooling, and socioeconomic status. Dichotomous categorisations representing high or low performance based on mid-point cut-offs for both verbal and non-verbal analogical reasoning are also included – these were created to compensate for the skewed nature of the data for verbal analogical reasoning for certain of the analyses as well as to extend the range of possible analyses for both variables (Howell, 2013).

6.6. Main phase: Directed analogical transfer

The first research question posed in the main phase of the study was to identify the rate of directed analogical transfer that occurred between a given source analogue based on the convergence schema and an isomorphic target problem in a sample of South African university students. In this instance, participants were provided with a general hint as to the possible relevance of the source material (a comprehension task based on the general and fire chief analogues) when developing solutions for the target problem – lighting a display in an aquarium (Catrambone & Holyoak, 1989; Gick & Holyoak, 1980; 1983; please refer to Appendix F).

Table 6.12 provides an overview of the number of distinct solutions generated by all participants in the main phase of the study for the aquarium problem. On average, participants generated approximately four distinct solutions ($M = 3.61$; $S = 1.73$). Although slightly lower, this was in line with the average number of solutions generated for the same problem in the pilot phase of the study.

Coding of the distinct solutions for the aquarium problem for the main phase of the study was carried out using the same coding framework that was developed in the pilot phase of the study. There were, however, two additional categories that were created to accommodate unique solution strategies (expert assistance and painting the tank or model dark) that were not suggested during the pilot phase of the study, bringing the total number of categories to thirty-two. Neither of the two additional categories were analogical in nature, and their inclusion had no impact on the scoring. The frequencies for each of the categories are presented in Table I.1 in Appendix I.

Table 6.12

Main phase: Number of distinct solutions per participant for the directed analogical transfer task (n = 608)

No. solutions (DT)	n (freq.)	% (total)	% (completed)
0	5	0.8	0.8
1	63	9.6	10.4
2	106	16.1	17.4
3	133	20.2	21.9
4	123	18.7	20.2
5	82	12.5	13.5
6	64	9.7	10.5
7	24	3.6	3.9
8	6	0.9	1.0
9	2	0.3	0.3
Completed	608	92.4	100
Missing	50	7.6	
Total	658	100	
Average	3.61		
Std. Dev.	1.727		

As in the pilot phase of the study, scoring for the *directed analogical transfer task* was based on the extent to which four key features of the convergence solution (reduced intensity, multiple lights, circular disposition, and simultaneous application) were present (Antonietti & Gioietta, 1995). A breakdown of the scores obtained in the main phase sample based on this categorisation is given in Table 6.13. Frequencies for the number of non-analogical, partial analogical, and full analogical solvers in the sample based on this categorisation are also presented in Table 6.13.

Excluding missing responses, approximately 31% (189) of the sample provided fully analogical solutions for the aquarium problem; approximately 38% (229) provided partially analogical solutions, and approximately 31% (190) provided non-analogical solutions. The rate of full analogical transfer observed in the main sample was thus much higher than the rate observed in the pilot study; this was, however, expected based on the shift in the nature of the task from spontaneous to directed (general hint). Interestingly, the rate of directed analogical transfer observed was lower than that typically seen in international samples (cf.

for example, Catrambone & Holyoak, 1989; Corkill & Fager, 1995; Cushen, 2012; Gick & Holyoak, 1980; 1983; Pedone et al., 2001).

Table 6.13

Main phase: Convergence category scores and classification for the directed analogical transfer task (n = 658)

Category		n	% (total)	% (completed)
Convergence category scores	0 (none)	190	28.9	31.3
	1 (reduced intensity)	94	14.3	15.5
	2 (multiple lights)	135	20.5	22.2
	3 (circular disposition)	160	24.3	26.3
	4 (simultaneous application)	29	4.4	4.8
	Missing	50	7.6	
Classification	0 (non-analogical)	190	28.9	31.3
	1 (partial analogical)	229	34.8	37.7
	2 (full analogical)	189	28.7	31.1
	Missing	50	7.6	

6.7. Main phase: Open analogical transfer

The second research question posed in the main phase of the study was to identify the rate of open analogical transfer that occurred between two problem isomorphs presented to a sample of South African university students without a pre-conceived solution strategy. In this instance, participants were provided with two problems (the thirsty bird and the ball-in-the-wall (Chen & Daehler, 1989)) that could potentially be solved analogously (please refer to Appendix F). Decisions regarding which solution strategies and the range of solution strategies that would be considered structurally similar, however, were only made following retrospective analysis of the categories provided by the participants. In this way it was hoped that a broader and potentially more realistic representation of analogical problem-solving skill would be captured (cf. Day & Goldstone, 2012; Holyoak, 2012; Lave, 1988; Lobato, 2006; Nokes, 2009; Novick & Holyoak, 1991).

Table 6.14 provides an overview of the number of distinct solutions generated by all participants in the main phase of the study for the thirsty-bird and ball-in-the-wall problems.

On average, participants generated approximately two distinct solutions ($M = 2.47$; $S = 1.09$) for the thirsty-bird problem and approximately three distinct solutions ($M = 2.73$; $S = 1.29$) for the ball-in-the-wall problem. Although slightly lower, these were in line with the average number of solutions generated for these same problems in the pilot phase of the study.

Table 6.14

Main phase: Number of distinct solutions per participant for the open analogical transfer task

No. solutions	Bird			Ball		
	n (freq.)	% (total)	% (completed)	n (freq.)	% (total)	% (completed)
0	4	0.6	0.7	3	0.5	0.5
1	102	15.5	17.2	106	16.1	17.9
2	217	33.0	36.7	159	24.2	26.9
3	176	26.7	29.7	174	26.4	29.4
4	75	11.4	12.7	98	14.9	16.6
5	15	2.3	2.5	37	5.6	6.3
6	2	0.3	0.3	10	1.5	1.7
7	0	0	0	5	0.8	0.8
10	1	0.2	0.2	0	0	0
Completed	592	90.0	100	592	90.0	100
Missing	66	10.0		66	10.0	
Total	658	100		658	100	
Average	2.47			2.73		
Std. Dev.	1.085			1.290		

Coding of the distinct solutions for both problems for the main phase of the study was carried out using the same coding frameworks that were developed in the pilot phase of the study. For the ball-in-the-wall problem, however, two additional categories were created to accommodate unique solution strategies (creating vibrations and selling objects to raise money to buy a new ball) that were not suggested during the pilot phase of the study, bringing the total number of categories for this problem to sixteen. The frequencies for each of the categories are presented in Table I.2 in Appendix I.

As in the pilot phase of the study, scoring for the *open analogical transfer task* was based on the retrospective identification of sets of structurally similar solution strategies. In addition to the four sets identified in the pilot study (*displacement*, *extraction*, *suction*, and

modification), a fifth set of structurally similar solutions between the two problems was identified based on one of the new categories created for the ball-in-the-wall problem. This strategy was *vibration* (represented by the suggestions of rolling the bottle over pebbles or rough ground or shaking it to displace water; and hitting the wall or using a cellphone signal to create vibrations to shake the ball loose from the wall). A breakdown of the number of participants presenting analogous solution sets and the frequency with which each solution set was given, as well as the rate of open analogical transfer based on having provided at least one of these sets, is given in Table 6.15.

Table 6.15

Main phase: Analogical solution frequencies and classification for the open analogical transfer task (n = 658)

Category		n	% (total)	% (completed)
Number of pairs	None	398	60.5	67.2
	One pair	158	24.0	26.7
	Two pairs	30	4.6	5.1
	Three pairs	5	0.8	0.8
	Four pairs	1	0.2	0.2
	Missing	66	10.0	
Pair 1	Displacement	135	20.5	22.8
Pair 2	Extraction	43	6.5	7.3
Pair 3	Suction	9	1.4	1.5
Pair 4	Modification	49	7.4	8.3
Pair 5	Vibration	1	0.2	0.2
Classification	0 (non-analogical)	398	60.5	67.2
	1 (analogical)	194	29.5	32.8
	Missing	66	10.0	

Excluding missing responses, approximately 33% (194) of the sample provided at least one set of analogous solutions to the two problems, whereas 67% (398) did not. The rate of open analogical transfer in the main sample was thus higher than the rate observed in the pilot sample (23%); this may have been as a result of the larger sample size. It is also worth noting that the rate of open analogical transfer was very similar to the rate of directed analogical transfer observed (31%) in the sample.

6.8. Main phase: The relationship between directed and open analogical transfer

The third research question posed in the main phase of the study was to explore the nature of the relationship between rates of directed and open analogical transfer within the same group of participants. As both directed and open transfer were scored categorically, a Chi-squared Test of Association was carried out to address this question (Howell, 2013).

The relationship between directed analogical transfer and open analogical transfer was significant ($\chi^2_2 = 16.74$; $p = .000$). The results for Cramer's V ($V = .172$; $p = .000$) also suggested that there was a significant relationship between the two variables although this was relatively weak (Howell, 2013). Observed values (frequencies) for each intersecting category across the two variables are shown in Table 6.16 (Howell, 2013). This table, in conjunction with the graph shown in Figure 6.3, indicated that relatively few participants (40 (7%)) who presented only non-analogical solutions for the directed transfer task presented at least one analogous solution set for the open transfer task. A relatively larger number of participants who presented partial and full analogical solutions respectively for the directed transfer task also presented at least one set of analogous solutions for the open transfer task (72 (13%) and 78 (14%) respectively).

Table 6.16

Main phase: Observed values for directed and open analogical transfer

		Open transfer		Total
		0 (non)	1 (analogous)	
Directed transfer	0 (non)	135 (23.7)	40 (7.0)	175 (30.8)
	1 (partial)	142 (25)	72 (12.7)	214 (37.6)
	2 (full)	102 (17.9)	78 (13.7)	180 (31.6)
Total		379 (66.6)	190 (33.4)	569 (100)

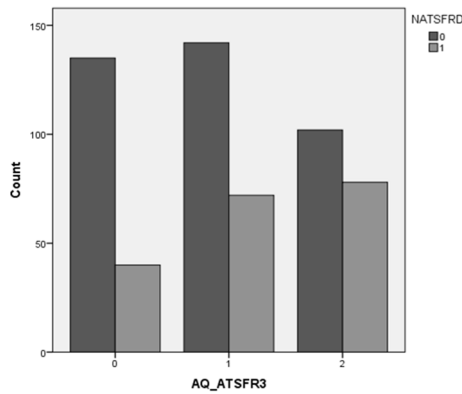


Figure 6.3. Clustered bar chart for directed and open analogical transfer.

This suggested that there was an increasing trend towards analogical solutions for the open transfer task across the non-analogical, partial analogical, and full analogical categories for the directed transfer task; and that approximately 40% of those who solved analogically for either task provided analogical solutions for both tasks.

Although weaker than ideal, the findings above do nevertheless suggest that there was a significant association between rates of directed and open analogical transfer in the sample. This provides a degree of conceptual support for the alternative, open methodological approach adopted; as well as preliminary evidence for viewing analogical problem solving as a reasonably stable and distinct skill.

6.9. Main phase: Relationships between non-verbal analogical reasoning and analogical problem solving

The first part of the fourth research question posed in the main phase of the study was to explore the nature of the relationships between both directed and open analogical problem solving and non-verbal analogical reasoning skill (represented by scores on the *Raven's Advanced Progressive Matrices (RAPM)*) in the sample. As both directed and open analogical transfer were categorical in nature, a one-way ANOVA with post-hoc testing (for directed) and an independent samples t-test (for open) were used to establish whether non-verbal analogical reasoning skill differed between the transfer categories for either type of analogical problem solving (Howell, 2013).

Table 6.17 presents the results of the one-way ANOVA carried out to establish if *RAPM* scores (representing non-verbal analogical reasoning) differed on the basis of having provided a non-analogical, partially analogical, or fully analogical solution for the directed analogical transfer task. Levene's Test for Equality of Variances indicated that the variances

between the groups were not significantly different ($p = .905$) thus the assumption of homogeneity of variance between the groups was met (Howell, 2013). There were significant differences between the means for the groups ($F_{(2; 605)} = 3.90; p = .021$) although the effect size for these differences was small ($\eta^2 = .013$).

Table 6.17

Main phase: One-way ANOVA for directed transfer and non-verbal analogical reasoning

Directed transfer	Levene's	SS	df	MS	F	p	η^2
RAPM	.905	275.377	2	137.688	3.899	.021	.013
		21366.898	605	35.317			

RAPM = Raven's Advanced Progressive Matrices (non-verbal analogical reasoning)

The results of the Fisher's Least Significant Difference (LSD) post-hoc comparisons (shown in Table 6.18) indicated that the mean *RAPM* score for those who provided non-analogical solutions ($M = 18.98; S = 6.01$) was significantly lower than the mean score for those who provided partial ($M = 20.30; S = 5.86; p = .024$) or full ($M = 20.55; S = 5.97; p = .010$) analogical solutions for the directed transfer task; although there was no significant difference between those who provided partial and full analogical solutions.

Table 6.18

Main phase: Post-hoc analyses for directed transfer and non-verbal analogical reasoning

Directed transfer		Mean Diff.	Std. Error	p	Lower CI	Upper CI
RAPM	0 – 1	1.322	0.583	.024	0.18	2.47
	0 – 2	1.571	0.611	.010	0.37	2.77
	1 – 2	0.249	0.584	.670	-0.90	1.40

RAPM = Raven's Advanced Progressive Matrices (non-verbal analogical reasoning)

Table 6.19 presents the results of the independent samples t-test carried out to establish if *RAPM* scores differed on the basis of having provided at least one analogical solution set for the open transfer task or not. Levene's Test indicated that homogeneity of variance between the groups could be assumed (Howell, 2013). There was a significant difference between the means for the two groups ($t_{590} = -3.33; p = .001$) although the effect size for this difference was small ($d = 0.289$). The mean *RAPM* score for those who provided at least one analogical solution set ($M = 21.13; S = 5.95$) was significantly higher than the mean score for those who did not ($M = 19.43; S = 5.80$).

Table 6.19

Main phase: Independent samples t-test for open transfer and non-verbal analogical reasoning

Open transfer	Levene's	t	df	p	d	Lower CI	Upper CI
RAPM	.912	-3.322	590	.001	.289	-2.708	-0.696

RAPM = Raven's Advanced Progressive Matrices (non-verbal analogical reasoning)

In addition to the above analyses, two Chi-square Tests of Association were conducted between the dichotomous variable representing high or low non-verbal analogical reasoning skill and the directed and open analogical transfer categories respectively. These were carried out as a form of verification and as a means through which to enhance understanding of the nature of the relationships between non-verbal analogical reasoning and directed and open analogical transfer, particularly strength and direction based on the Phi Coefficient and Cramer's V estimates (Howell, 2013; Huck, 2008). The results confirmed that non-verbal analogical reasoning skill was significantly associated with open analogical transfer ($\chi^2_1 = 9.52$; $p = .002$; $\phi = .127$; $p = .002$), although the relationship established was weak. In contrast, the association between non-verbal analogical reasoning skill as a dichotomous variable and directed analogical transfer was not significant ($\chi^2_2 = 1.40$; $p = .497$; $V = .048$; $p = .497$) (for the relevant tables of observed values (frequencies) please refer to Table J.1 and Table J.2 in Appendix J).

Taken together, the results suggest that non-verbal analogical reasoning skill was related to open analogical problem solving, with those participants who presented analogical solutions exhibiting significantly higher levels of non-verbal analogical reasoning skill. It is important to note, however, that the effect size for this was small. There were conflicting results regarding the relationship between non-verbal analogical reasoning skill and directed analogical problem solving. One analysis indicated that there was no significant association between the two whereas the second analysis suggested there were significant differences in non-verbal analogical reasoning skill between non-analogical and partially or fully analogical problem solvers, however the effect size for this was very small.

6.10. Main phase: Relationships between verbal analogical reasoning and analogical problem solving

The second part of the fourth research question posed in the main phase of the study was to explore the nature of the relationships between both directed and open analogical problem solving and verbal analogical reasoning skill (represented by scores on the *revised*

verbal analogical reasoning task) in the sample. As both directed and open analogical transfer were categorical in nature and scores for the *verbal analogical reasoning task* were skewed, a non-parametric Kruskal-Wallis H test (for directed) and a non-parametric Mann-Whitney U test (for open) were used to establish whether verbal analogical skill differed between the transfer categories for either type of analogical problem solving (Howell, 2013).

The results of the Kruskal-Wallis H test indicated that there were significant differences in performance (mean ranks) between those who provided non-analogical ($MR = 259.14$), partially analogical ($MR = 305.62$), and fully analogical ($MR = 348.75$) solutions for the directed analogical transfer task ($\chi^2_2 = 25.13$; $p = .000$). A series of Mann-Whitney U tests carried out as post-hoc analyses to establish which groups differed is presented in Table 6.20. The results of these tests indicated that all three of the groups were significantly different to one another (non-partial: $U = 18373.50$; $p = .006$; non-full: $U = 12717.50$; $p = .000$; partial-full: $U = 18515.50$; $p = .010$) however the effect sizes for all three sets of comparisons were small ($r = .135$; $r = .255$; and $r = .126$ respectively).

Table 6.20

Main phase: Post-hoc analyses for directed transfer and verbal analogical reasoning

Directed transfer		Mean Rank	MWU	Z	p	r (ES)
RVRT-21	0 – 1	192.20 224.77	18373.50	-2.764	.006	.135
	0 – 2	162.43 217.71	12717.50	-4.955	.000	.255
	1 – 2	195.85 226.03	18515.50	-2.569	.010	.126

RVRT-21 = Revised Verbal Reasoning Task (verbal analogical reasoning)

The result of the Mann-Whitney U test carried out to establish if verbal analogical reasoning performance differed between those participants who identified at least one analogous set of solutions for the open transfer task and those who did not was significant ($U = 27440.00$; $p = .000$) although the effect size for this comparison was small ($r = .237$). The mean ranks suggested that those participants who identified at least one analogous set of solutions ($MR = 354.06$) performed significantly better than those who did not ($MR = 268.44$).

In addition to the above analyses, two Chi-square Tests of Association were conducted between the dichotomous variable representing high or low verbal analogical

reasoning skill and the directed and open analogical transfer categories respectively. These were carried out as a form of verification and as a means through which to enhance understanding of the nature of the relationships between verbal analogical reasoning and directed and open analogical transfer, particularly strength and direction based on the Phi Coefficient and Cramer's V estimates (Howell, 2013; Huck, 2008). The results confirmed that verbal analogical reasoning skill was significantly associated with both directed ($\chi^2_2 = 14.15$; $p = .001$; $V = .153$; $p = .001$) and open ($\chi^2_1 = 23.97$; $p = .000$; $\phi = .201$; $p = .000$) analogical transfer, although these relationships were weak (for the relevant tables of observed values (frequencies) please refer to Table J.3 and Table J.4 in Appendix J). Taken together, the results suggest that verbal analogical reasoning skill was related to both directed and open analogical problem solving, with those participants who presented analogical solutions for either task exhibiting significantly higher levels of verbal analogical reasoning skill. It is important to note, however, that the effect sizes for these were small.

6.11. Main phase: Relationships between heuristic strategy preference and analogical problem solving

The fifth research question posed in the main phase of the study was to explore the nature of the relationships between both directed and open analogical problem solving and self-reported heuristic strategy preference in the sample. A series of one-way ANOVAs with post-hoc testing (for directed) and independent samples t-tests (for open) were used to establish whether self-reported heuristic strategy preference (analogy, step-by-step/visualisation, and free production/combining preference) differed between the transfer categories for either type of analogical problem solving (Howell, 2013).

Table 6.21 presents the results of the one-way ANOVAs carried out to establish if heuristic strategy preference differed on the basis of having provided a non-analogical, partially analogical, or fully analogical solution for the directed analogical transfer task. For all three tests, the Levene's Tests indicated that homogeneity of variance between the groups could be assumed (Howell, 2013). There were no significant differences between the means of the groups for either analogy preference or free production/combining preference. There were, however, significant differences between the means of the groups for step-by-step/visualisation preference ($F_{(2; 598)} = 4.00$; $p = .019$), although the effect size for these differences was small ($\eta^2 = .013$).

The results of the Fisher's Least Significant Difference (LSD) post-hoc comparisons (shown in Table 6.22) indicated that the mean step-by-step/visualisation preference score for those who provided non-analogical solutions ($M = 17.82$; $S = 3.53$) was significantly higher

than the mean score for those who provided partial ($M = 17.08$; $S = 3.78$; $p = .042$) or full ($M = 16.79$; $S = 3.58$; $p = .006$) analogical solutions for the directed transfer task; although there was no significant difference between those who provided partial and full analogical solutions.

Table 6.21

Main phase: One-way ANOVAs for directed transfer and heuristic strategy preference

Directed transfer	Levene's	SS	df	MS	F	p	η^2
HSP Analogy	.770	2.223	2	1.112	0.174	.840	.001
		3813.621	598	6.377			
HSP Step-by-step/ visualisation	.414	105.967	2	52.983	3.995	.019	.013
		7930.156	598	13.261			
HSP free production/ combining	.576	26.164	2	13.082	0.800	.450	.003
		9779.038	598	16.353			

HSP = heuristic strategy preference

Table 6.22

Main phase: Post-hoc analyses for directed transfer and heuristic strategy preference

Directed transfer		Mean Diff.	Std. Error	p	Lower CI	Upper CI
HSP Step-by-step/ visualisation	0 – 1	0.735	0.360	.042	0.03	1.44
	0 – 2	1.027	0.376	.006	0.29	1.76
	1 – 2	0.292	0.360	.418	-0.41	1.00

HSP = heuristic strategy preference

Table 6.23

Main phase: Independent samples t-tests for open transfer and heuristic strategy preference

Open transfer	Levene's	t	df	p	d	Lower CI	Upper CI
HSP Analogy	.066	-1.528	587	.127	.138	-0.766	0.096
HSP Step-by-step/ visualisation	.201	0.000	587	.999	.000	-0.631	0.631
HSP Free production/ combining	.547	0.943	587	.346	.083	-0.358	1.020

HSP = heuristic strategy preference

Table 6.23 presents the results of the independent samples t-tests carried out to establish if self-reported heuristic strategy preference differed on the basis of having

provided at least one analogical solution set for the open transfer task or not. For all three tests, the Levene's Tests indicated that homogeneity of variance between the groups could be assumed (Howell, 2013). There were no significant differences between the means of the groups for any of the preference clusters (analogy, step-by-step/visualisation, and free production/combining).

Although originally designed to represent five broader clusters of problem-solving heuristic preferences (cf. Antonietti et al., 2000), each statement included in the *self-reported heuristic strategy preference scale* also represented a distinct problem-solving heuristic method or behaviour in its own right. Additional analyses exploring the nature of the relationships between these and both open and directed transfer were therefore carried out in order to enhance understanding and address the posed research question in more detail. These analyses consisted of a further series of one-way ANOVAs with post-hoc comparisons (for directed) and independent samples t-tests (for open) in which the scores from each individual item included in the *self-reported heuristic strategy preference scale* were used as the dependent variables (Howell, 2013). The only exception to this was for Item 9, where the skewed nature of the data required that non-parametric alternatives (the Kruskal-Wallis H test for directed transfer and the Mann-Whitney U test for open transfer) be used instead (Howell, 2013).

The results of the Kruskal-Wallis H test for Item 9 and most of the one-way ANOVAs for the other items were non-significant (please refer to Table J.5 and Table J.6 in Appendix J), indicating few differences in preferred problem-solving heuristic methods or behaviours between those who provided non-analogical, partially analogical, or fully analogical solutions for the directed transfer task. Two exceptions were the results for Item 13 (systematically plan and order steps) and Item 17 (rule out aspects that are seemingly not relevant) – shown in Table 6.24. For both of these items, the Levene's Tests indicated that homogeneity of variance between the groups could be assumed (Howell, 2013) and there were significant differences between the means of the groups (Item 13: $F_{(2; 594)} = 3.22$; $p = .041$; Item 17: $F_{(2; 593)} = 5.80$; $p = .003$), although the effect sizes were small ($\eta^2 = .011$ and $\eta^2 = .019$ respectively).

Table 6.24

Main phase: One-way ANOVAs for directed transfer and heuristic preference items

Directed transfer	Levene's	SS	df	MS	F	p	η^2
HSP	.436	8.153	2	4.077	3.215	.041	.011
Item 13		753.086	594	1.268			
HSP	.400	13.895	2	6.947	5.801	.003	.019
Item 17		710.233	593	1.198			

HSP = heuristic strategy preference

The results of the Fisher's Least Significant Difference (LSD) post-hoc comparisons (shown in Table 6.25) indicated that for Item 13, the mean score for those who provided non-analogical solutions ($M = 3.68$; $S = 1.10$) was significantly higher than the mean score for those who provided partial ($M = 3.44$; $S = 1.17$; $p = .035$) or full ($M = 3.41$; $S = 1.10$; $p = .022$) analogical solutions for the directed transfer task; although there was no significant difference between those who provided partial and full analogical solutions. For Item 17, the mean score for those who provided full analogical solutions ($M = 3.61$; $S = 1.03$) was significantly higher than the mean score for those who provided partial analogical ($M = 3.32$; $S = 1.11$; $p = .007$) or non-analogical ($M = 3.26$; $S = 1.13$; $p = .002$) solutions for the directed transfer task; although there was no significant difference between those who provided partial analogical and non-analogical solutions.

Table 6.25

Main phase: Post-hoc analyses for directed transfer and heuristic preference items

Directed transfer		Mean Diff.	Std. Error	p	Lower CI	Upper CI
HSP Item 13	0 – 1	0.236	0.111	.035	0.02	0.46
Systematically plan and order steps	0 – 2	0.267	0.116	.022	0.04	0.50
	1 – 2	0.031	0.112	.783	-0.19	0.25
HSP Item 17	0 – 1	0.065	0.109	.553	-0.15	0.28
Rule out aspects seemingly not relevant	0 – 2	0.360	0.114	.002	0.14	0.58
	1 – 2	0.295	0.108	.007	0.08	0.51

HSP = heuristic strategy preference

Table 6.26

Main phase: Independent samples t-tests for open transfer and heuristic preference items

Open transfer	Levene's	t	df	p	d	Lower CI	Upper CI
HSP Item 4	.861	-2.117	585	.035	.181	-0.435	-0.016
HSP Item 11	.738	2.137	586	.033	.190	0.018	0.435
HSP Item 17	.018	-2.169	426.723	.031	.193	-0.388	-0.019

HSP = heuristic strategy preference

The results of the Mann-Whitney U test for Item 9 and most of the independent sample t-tests for the other items were non-significant (please refer to Table J.7 and Table J.8 in Appendix J), indicating few differences in preferred problem-solving heuristic methods or behaviours between those who provided at least one set of analogical solutions for the open analogical transfer task and those who did not. There were, however, three exceptions where significant differences between the means for the two groups were observed, as shown in Table 6.26.

For Items 4 and 11, the Levene's Tests indicated that homogeneity of variance between the groups could be assumed (Howell, 2013). For Item 11 (create many ideas then analyse them to choose the best one), participants who provided at least one set of analogical solutions ($M = 2.95$; $S = 1.21$) scored significantly lower ($t_{586} = 2.14$; $p = .033$) than participants who did not ($M = 3.18$; $S = 1.21$), although the effect size for this was small ($d = .190$). In contrast, for Item 4 (represent a problem differently e.g. pictures or graphs), participants who provided at least one set of analogical solutions ($M = 3.12$; $S = 1.21$) scored significantly higher ($t_{585} = -2.12$; $p = .035$) than participants who did not ($M = 2.90$; $S = 1.22$), although the effect size was again small ($d = .181$). For Item 17 (rule out aspects that are seemingly not relevant), the Levene's Tests indicated that homogeneity of variance between the groups could not be assumed as the variances between the two groups were significantly different ($p = .018$) (Howell, 2013). As a result, a method of compensating for unequal variances was used when conducting the independent samples t-test for this variable (hence the unusual degree of freedom) (Howell, 2013). The results suggested that there was a significant difference between the groups ($t_{427.72} = -2.17$; $p = .031$), although the effect size for this was small ($d = .193$). Participants who provided at least one set of analogical solutions for the open transfer task ($M = 3.53$; $S = 1.02$) scored significantly higher than participants who did not ($M = 3.32$; $S = 1.16$).

Taken together, the results indicate that there was no significant relationship between preference for analogy as a problem solving heuristic strategy and either directed or open analogical transfer in the sample. There was, however, a significant difference in step-by-step/ visualisation preference between non-analogical, partial analogical, and full analogical solvers for the directed transfer task; those with the least degree of preference for this cluster of strategies performed best in terms of directed analogical transfer. Certain individual problem solving heuristic methods or behaviours were also identified as related to either directed or open analogical transfer, although only a preference for discarding seemingly irrelevant aspects of the problem was associated with both forms of analogical problem solving.

6.12. Main phase: Relationships between modal preference and analogical problem solving

Although not originally conceptualised as part of the research questions, the relationships between both directed and open analogical problem solving and modal preference were also explored. This was useful to consider as all of the measures/ tasks were presented to participants in written form, and the manner in which they preferred to receive information for learning or activity purposes could thus have played a role in their performance (Matthews, 1991; Pettigrew & Buell, 1989). A series of one-way ANOVAs with post-hoc testing (for directed) and independent samples t-tests (for open) were used to establish whether modal preference (listening, reading, iconic, and direct experience preference) differed between the transfer categories for either type of analogical problem solving (Howell, 2013).

Table 6.27 presents the results of the one-way ANOVAs carried out to establish if modal preference differed on the basis of having provided a non-analogical, partially analogical, or fully analogical solution for the directed analogical transfer task. For all four tests, the Levene's Tests indicated that homogeneity of variance between the groups could be assumed (Howell, 2013). There were no significant differences between the means of the groups for any of the modal preferences, suggesting that this was not a factor that was related to performance on the directed analogical problem solving task.

Table 6.27

Main phase: One-way ANOVAs for directed transfer and modal preference

Directed transfer	Levene's	SS	df	MS	F	p	η^2
MP Listening	.545	20.759	2	10.379	0.643	.526	.002
		9764.794	605	16.140			
MP Reading	.355	67.509	2	33.754	1.352	.259	.004
		15099.661	605	24.958			
MP Iconic	.166	80.735	2	40.368	1.855	.157	.006
		13167.684	605	21.765			
MP Direct Experience	.158	36.176	2	18.088	0.848	.429	.003
		12905.796	605	21.332			

MP = modal preference

Table 6.28 presents the results of the independent samples t-tests carried out to establish if modal preference differed on the basis of having provided at least one analogical solution set for the open transfer task or not. For listening, reading, and direct experience preference, the Levene's Tests indicated that homogeneity of variance between the groups could be assumed (Howell, 2013). For iconic preference, however, the Levene's Test indicated that homogeneity of variance between the groups could not be assumed ($p = .009$) and thus a method of compensating for unequal variances was used when conducting the independent samples t-test for this variable (Howell, 2013). There were no significant differences between the means of the two groups for either reading preference or direct experience preference. There were, however, significant differences between the means of the two groups for listening preference ($t_{590} = 2.38$; $p = .018$) and iconic preference ($t_{436.16} = -2.26$; $p = .024$), although the effect sizes in both cases were small ($d = .210$ and $d = .191$ respectively).

Table 6.28

Main phase: Independent samples t-tests for open transfer and modal preference

Open transfer	Levene's	t	df	p	d	Lower CI	Upper CI
MP Listening	.872	2.380	590	.018	.210	0.146	1.525
MP Reading	.347	1.779	590	.076	.156	-0.080	1.615
MP Iconic	.009	-2.258	436.160	.024	.191	-1.640	-0.113
MP Direct Experience	.105	-0.142	590	.887	.013	-0.859	0.743

MP = modal preference

The mean listening preference score for those who provided at least one analogical solution set ($M = 15.14$; $S = 3.95$) was significantly lower than the mean score for those who did not ($M = 15.98$; $S = 4.04$). In contrast, the mean iconic preference score for those who provided at least one analogical solution set ($M = 16.98$; $S = 4.21$) was significantly higher than the mean score for those who did not ($M = 16.11$; $S = 4.86$). These results suggest that a preference for receiving information in visual form was linked to successful open analogical transfer in the sample. The alignment between this finding and the finding that a heuristic behaviour preference for representing information differently (for example, in the form of a picture or graph) was also linked to successful open analogical transfer is particularly interesting to note.

6.13. Main phase: Relationships between demographic variables and analogical problem solving

The sixth research question posed in the main phase of the study was to explore the nature of the relationships between both directed and open analogical problem solving and various demographic characteristics of the sample. The characteristics that were focused on were gender, home language, type of schooling, and socioeconomic status. As all of these variables were categorical in nature, a series of Chi-squared Tests of Association were carried out to address the research question (Howell, 2013).

The results of the Chi-squared Tests of Association exploring the relationships between directed analogical problem solving and the demographic variables are given in Table 6.29. The relationship between type of schooling and directed analogical transfer was not significant. Significant relationships were established between gender and directed analogical transfer ($\chi^2_2 = 11.29$; $p = .004$; $V = .136$; $p = .004$); home language and directed analogical transfer ($\chi^2_2 = 23.27$; $p = .000$; $V = .196$; $p = .000$); and socioeconomic status and directed analogical transfer ($\chi^2_4 = 13.86$; $p = .008$; $V = .107$; $p = .008$). In all cases, the relationships established were significant and relatively weak.

Table 6.29

Main phase: Chi-squared tests of association for directed transfer and demographics

Directed transfer	χ^2	df	p	Cramer's V	Cramer's p
Gender	11.292	2	.004	.136	.004
Home language	23.265	2	.000	.196	.000
Type of schooling	4.463	2	.107	.087	.107
Socioeconomic status	13.864	4	.008	.107	.008

As illustrated in the tables of observed values (please refer to Table J.9, Table J.10, Table J.11, and Table J.12 in Appendix J), 34% of all females in the sample provided full analogical solutions for the directed transfer task whereas only 23% of all males did so. For home language, 38% of all English home-language speakers produced full analogical solutions for the directed transfer task in comparison to 22% of all other home-language speakers. For socioeconomic status, 22% of all those categorised as low socioeconomic status in the sample produced full analogical solutions for the directed transfer task, in contrast to 36% of all those categorised as mid-level socioeconomic status and 36% of all those categorised as high level socioeconomic status.

The results of the Chi-squared Tests of Association exploring the relationships between open analogical problem solving and the demographic variables are given in Table 6.30. The relationship between gender and open analogical transfer was not significant. Significant relationships were established between home language and open analogical transfer ($\chi^2_1 = 15.02$; $p = .000$; $\phi = -.159$; $p = .000$); type of schooling and open analogical transfer ($\chi^2_1 = 25.56$; $p = .000$; $\phi = .211$; $p = .000$); and socioeconomic status and open analogical transfer ($\chi^2_2 = 18.08$; $p = .000$; $V = .175$; $p = .000$). In all cases, the relationships established were significant and relatively weak.

Table 6.30

Main phase: Chi-squared tests of association for open transfer and demographics

Open transfer	χ^2	df	p	ϕ	ϕp	Cramer's V	Cramer's p
Gender	0.705	1	.401	-.035	.401	-	-
Home language	15.016	1	.000	-.159	.000	-	-
Type of schooling	25.555	1	.000	.211	.000	-	-
Socioeconomic status	18.079	2	.000	-	-	.175	.000

As illustrated in the tables of observed values (please refer to Table J.13, Table J.14, Table J.15, and Table J.16 in Appendix J), 39% of all English home-language speakers produced at least one analogical solution set for the open transfer task in comparison to 24% of all other home-language speakers. For type of schooling, 24% of all those with a government school background produced at least one analogical solution set for the open transfer task, whereas 44% of all those with a private school background did so. For socioeconomic status, 24% of all those categorised as low socioeconomic status in the sample produced at least one analogical solution set for the open transfer task, in contrast to

31% of all those categorised as mid-level socioeconomic status and 44% of all those categorised as high level socioeconomic status.

6.14. Main phase: Prediction and multicollinearity

The seventh and final research question posed in the study was to establish the extent to which the other core variables (verbal and non-verbal analogical reasoning, self-reported heuristic strategy preference, and the demographic characteristics) were predictive of both directed and open analogical problem solving performance in the sample. In order to address this question, a series of multinomial (for directed transfer) and binomial (for open transfer) logistic regressions were carried out (Hosmer & Lemeshow, 2000; Howell, 2013; Huck, 2008). Prior to running the logistic regression analyses, it was first necessary to establish the nature of the relationships between each of the intended predictor variables in order to avoid issues of multicollinearity (Hosmer & Lemeshow, 2000; Huck, 2008). Multicollinearity occurs if strong relationships exist between two or more of the predictor variables; this does not affect the overall model but may make it difficult to accurately interpret the role played by individual predictors (Huck, 2008; Mason & Perreault, 1991). The relationships between verbal analogical reasoning, non-verbal analogical reasoning, analogy preference, step-by-step/visualisation preference, free production/combining preference, gender, home language, type of schooling, and socioeconomic status were therefore established using a series of one-way ANOVAs, Kruskal-Wallis H tests, two independent samples t-tests, Mann-Whitney U tests, Chi-squared Tests of Association, Pearson's correlation coefficients, and Spearman's rank correlation coefficients as appropriate (Howell, 2013). As these analyses were not a focal area within the study, only those relationships that were identified as significant are reported briefly below. It is important to note that the skewed nature of the data for verbal analogical reasoning prevented it from being entered into the regression in continuous form (Allison, 1999). In order to resolve this issue, and as discussed earlier, a dichotomous version of the variable (high or low performance based on a mid-point cut-off) was created that could be entered into the model as a 'dummy' variable (Allison, 1999; Huck, 2008).

The relationship between verbal and non-verbal analogical reasoning was significant, positive, and weak-moderate ($r_s = 0.387$; $p = .000$); there was also a significant difference in non-verbal analogical reasoning performance (*RAPM* scores) between the high and low verbal analogical reasoning groups with a moderate effect size ($t_{656} = -7.20$; $p = .000$; $d = .566$). There were significant differences in non-verbal analogical reasoning performance on the basis of home language ($t_{655} = 4.51$; $p = .000$; $d = .354$) and socioeconomic status ($F_{(2; 654)} = 8.40$; $p = .000$; $\eta^2 = .025$) although the effect sizes were small.

Both step-by-step/visualisation preference ($r_s = -.094$; $p = .016$) and free production/combining preference ($r_s = -.137$; $p = .000$) were significantly, negatively, and weakly related to verbal analogical reasoning performance. Step-by-step/visualisation preference ($t_{647} = 2.54$; $p = .011$; $d = .202$) and free production/combining preference ($t_{647} = 3.15$; $p = .002$; $d = .249$) also differed significantly on the basis of high or low verbal analogical reasoning performance, although the effect sizes were small. There were significant differences in verbal analogical reasoning performance on the basis of type of schooling ($U = 38447.00$; $p = .000$; $r = .202$); home language ($U = 32718.00$; $p = .000$; $r = .349$); and socioeconomic status ($\chi^2_2 = 33.54$; $p = .000$). All of the effect sizes for the post-hoc analyses (Mann-Whitney U tests) for socio-economic status were small, as were the effect sizes for type of schooling and home language. Significant associations between verbal analogical reasoning as a categorical variable (high or low performance) and home language ($\chi^2_1 = 54.77$; $p = .000$; $\phi = -.289$; $p = .000$), type of schooling ($\chi^2_1 = 12.95$; $p = .000$; $\phi = .143$; $p = .000$), and socioeconomic status ($\chi^2_2 = 20.80$; $p = .000$; $V = .178$; $p = .000$) were also established.

There were significant differences in both step-by-step/visualisation preference ($t_{646} = -3.15$; $p = .002$; $d = .251$) and free production/combining preference ($t_{646} = -4.98$; $p = .000$; $d = .396$) on the basis of home language although the effect sizes were small. Free production/combining preference also differed significantly on the basis of socioeconomic status ($F_{(2, 645)} = 3.72$; $p = .025$; $\eta^2 = .011$). Step-by-step/visualisation preference and free production/combining preference were significantly, positively, and weakly-moderately related to one another ($r = .397$; $p = .000$); and both were significantly, positively, and weakly related to analogy preference ($r = .309$; $p = .000$; and $r = .249$; $p = .000$ respectively). There were also significant associations between home language and type of schooling ($\chi^2_1 = 62.02$; $p = .000$; $\phi = -.313$; $p = .000$); home language and socioeconomic status ($\chi^2_2 = 142.13$; $p = .000$; $V = .465$; $p = .000$); and type of schooling and socioeconomic status ($\chi^2_2 = 46.41$; $p = .000$; $V = .271$; $p = .000$).

These results suggested that the majority of the predictor variables were related to one another. In order to establish the extent to which these relationships would be problematic if the predictors were entered simultaneously into the same regression model, variance inflation factors (VIF), tolerance estimates, and condition indices were calculated for different predictor combinations (Allison, 1999). A maximum cut-off of two for the variance inflation factors, a minimum cut-off of zero-point-four for the tolerance estimates, and a maximum cut-off of thirty for the condition indices was applied (cf. Allison, 1999; IDRE,

2016; Lomax & Hahs-Vaughn, 2012). On this basis, it proved acceptable to enter verbal and non-verbal analogical reasoning, all three of the heuristic strategy preference subscales, gender, and one of home language, type of schooling, and socioeconomic status into the same regression model. If home language, type of schooling, and socioeconomic status were entered simultaneously in any combination, however, at least one of the multicollinearity indicator cut-offs was violated. As a result, it was necessary to run each of these three variables separately (in combination with the other predictor variables) thus a total of six regression models (three for directed transfer and three for open transfer) were created.

6.15. Main phase: Predicting directed transfer

In order to establish the extent to which verbal and non-verbal analogical reasoning, analogy preference, step-by-step/visualisation preference, free production/combining preference, gender, and one of home language, type of schooling, and socioeconomic status could be used to predict directed analogical problem solving, three multinomial logistic regressions were run (Hosmer & Lemeshow, 2000; Howell, 2013; Huck, 2008).

6.15.1. Predicting directed transfer with home language as a predictor.

The first regression model for directed transfer included home language as one of the predictors (independent variables). As shown in Table K.1 in Appendix K, the number of valid cases in this analysis was 600. This indicated that the ratio of cases to independent variables was 85.7:1 (600:7). The minimum acceptable ratio of cases to independent variables is 10:1 and the preferred ratio is 20:1, thus the ratio of cases to independent variables in this analysis was good (Hosmer & Lemeshow, 2000; Schwab, 2002).

As shown in Table 6.31, the result of the likelihood ratio test for the model indicated that the full model (with the predictor variables included) acted as a significantly better predictor of directed transfer than the intercept-only model ($\chi^2_{14} = 55.52; p = .000$). In other words, a significant relationship between directed transfer as the dependent variable and the particular combination of independent (predictor) variables was established (LAERD, 2016; Schwab, 2002). The results of the Pearson ($\chi^2_{1178} = 1197.55; p = .339$) and deviance ($\chi^2_{1178} = 1249.90; p = .071$) goodness-of-fit tests were also non-significant, which suggested that the data fitted the model well. Although pseudo r-squared measures were calculated (Cox and Snell: .088; Nagelkerke: .100; McFadden: .042), these are extremely difficult to interpret and are thus not discussed further (LAERD, 2016; Peng & So, 2002; Schwab, 2002).

Table 6.31

Main phase: Likelihood ratio test for model fit – directed transfer model one (home language)

Model	Model Fitting Criteria	Likelihood Ratio Tests		
		χ^2	df	p
Directed transfer	-2 Log Likelihood			
Intercept only	1309.575			
Final	1254.060	55.515	14	.000

An alternate method to judge the utility of the regression model is to compare known group membership for the dependent variable and predicted group membership based on the logistic model – this provides an estimate of the classification accuracy for the model (Schwab, 2002). If the classification accuracy exceeds the rate of accuracy that could be achieved by chance by twenty-five percent or more, the model can be regarded as useful (Schwab, 2002). In this instance, the proportional by-chance-accuracy-rate was 33.6%; the minimum cut-off for a twenty-five percent or more improvement was thus 42% (Schwab, 2002). As shown in Table 6.32, the predicted classification accuracy rate was 45%, thus the model could be regarded as useful (Hosmer & Lemeshow, 2000; Schwab, 2002).

Table 6.32

Main phase: Predicted classification accuracy – directed transfer model one (home language)

Classification				
Directed transfer	Predicted			% Correct
Observed	0	1	2	
0	86	69	32	46.0
1	54	104	67	46.2
2	33	75	80	42.6
Overall %	28.8	41.3	29.8	45.0

As shown in Table 6.33, the multicollinearity indicators fell within the specified ranges (above 0.4 for tolerance, below 2 for VIF, and below 30 for CI; cf. Allison, 1999; IDRE, 2016; Lomax & Hahs-Vaughn, 2012). This was supported by the standard error estimates for the independent variables (shown in Table K.2 in Appendix K), all of which were less than two indicating a lack of multicollinearity (Schwab, 2002). Table 6.33 also indicates that step-by-step/visualisation preference ($\chi^2_2 = 8.44$; $p = .015$), gender ($\chi^2_2 = 14.68$; $p = .001$); and home language ($\chi^2_2 = 16.10$; $p = .000$) were the only independent variables that acted as significant predictors of directed transfer.

Table 6.33

Main phase: Predictors for directed transfer model one (home language)

Effect Directed T.	Model Fitting	Likelihood Ratio Tests			Collinearity		
	Criteria	χ^2	df	p	Tol.	VIF	C.I.
Intercept	1254.060	0.000	0	.	.	.	1.000
RAPM	1257.387	3.327	2	.190	0.917	1.090	7.058
HSP ST/V	1262.500	8.440	2	.015	0.782	1.278	10.338
HSP FP/C	1256.819	2.759	2	.252	0.800	1.250	10.795
HSP ANL	1254.510	0.450	2	.799	0.878	1.139	11.148
RVRT-2	1259.016	4.956	2	.084	0.859	1.164	15.092
GNDR	1268.738	14.678	2	.001	0.986	1.014	17.725
HLANG	1270.160	16.100	2	.000	0.884	1.131	28.020

RAPM = Raven's Advanced Progressive Matrices (non-verbal analogical reasoning); RVRT-2 = Revised Verbal Analogical Reasoning Task (verbal analogical reasoning - dichotomous); HSP ST/V = step-by-step/ visualisation heuristic strategy preference; HSP FP/C = free production/ combining heuristic strategy preference; HSP ANL = analogy heuristic preference; GNDR = gender; HLANG = home language

Table K.2 in Appendix K presents the significance and odds-ratios for each individual continuous independent variable and each individual level of the categorical independent variables (Huck, 2008; IDRE, 2016). Step-by-step/visualisation preference was significant for distinguishing both partial ($\chi^2_1 = 5.25$; $p = .022$; $OR = 0.929$) and full ($\chi^2_1 = 7.36$; $p = .007$; $OR = 0.912$) analogical solvers from non-analogical solvers; participants with higher step-by-step/visualisation preference scores were less likely to be in either the partial or full analogical solution groups. Gender was also significant for distinguishing both partial ($\chi^2_1 = 4.83$; $p = .028$; $OR = 0.610$) and full ($\chi^2_1 = 14.05$; $p = .000$; $OR = 0.385$) analogical solvers from non-analogical solvers; male participants were less likely to be in either the partial or full analogical solution groups. Home language was only significant for distinguishing between full analogical solvers and non-analogical solvers ($\chi^2_1 = 15.67$; $p = .000$; $OR = 2.522$); English home language speakers were more likely to be in the full analogical solution group.

6.15.2. Predicting directed transfer with type of schooling as a predictor.

The second regression model for directed transfer included type of schooling as one of the predictors (independent variables). As shown in Table K.3 in Appendix K, the number of valid cases in this analysis was 584. The ratio of cases to independent variables was 83.4:1 (584:7) which was good (Hosmer & Lemeshow, 2000; Schwab, 2002).

As shown in Table 6.34, the result of the likelihood ratio test for the model indicated that the full model acted as a significantly better predictor of directed transfer than the intercept-only model ($\chi^2_{14} = 37.51$; $p = .001$). The result of the Pearson ($\chi^2_{1146} = 1165.04$; $p = .341$) goodness-of-fit test was also non-significant, which suggested that the data fitted the model well. The deviance ($\chi^2_{1146} = 1235.58$; $p = .033$) goodness-of-fit test, however, was significant suggesting the data did not fit the model well. The pseudo r-squared measures were .062 for Cox and Snell; .070 for Nagelkerke; and .029 for McFadden (LAERD, 2016; Peng & So, 2002; Schwab, 2002). The proportional by-chance-accuracy-rate was 33.6%; the minimum cut-off for a twenty-five percent or more improvement was thus 42%. As shown in Table 6.35, the predicted classification accuracy rate was 45%, thus the model could be regarded as useful (Hosmer & Lemeshow, 2000; Schwab, 2002).

Table 6.34

Main phase: Likelihood ratio test for model fit – directed transfer model two (type of schooling)

Model	Model Fitting Criteria	Likelihood Ratio Tests		
		χ^2	df	p
Directed transfer	-2 Log Likelihood			
Intercept only	1275.862			
Final	1238.350	37.512	14	.001

Table 6.35

Main phase: Predicted classification accuracy – directed transfer model two (type of schooling)

Directed transfer	Classification			% Correct
	0	1	2	
Observed				
0	77	71	32	42.8
1	48	122	49	55.7
2	32	88	65	35.1
Overall %	26.9	48.1	25.0	45.2

Table 6.36

Main phase: Predictors for directed transfer model two (type of schooling)

Effect Directed T.	Model Fitting	Likelihood Ratio Tests			Collinearity		
	Criteria	χ^2	df	p	Tol.	VIF	C.I.
Intercept	1238.350	0.000	0	.	.	.	1.000
RAPM	1241.290	2.940	2	.230	0.933	1.071	8.164
HSP ST/V	1245.080	6.730	2	.035	0.780	1.283	8.975
HSP FP/C	1240.964	2.614	2	.271	0.805	1.242	10.863
HSP ANL	1238.687	0.336	2	.845	0.871	1.148	11.180
RVRT-2	1246.422	8.072	2	.018	0.903	1.107	15.062
GNDR	1251.677	13.327	2	.001	0.985	1.016	17.561
TSCHL	1240.651	2.301	2	.316	0.973	1.028	27.673

RAPM = Raven's Advanced Progressive Matrices (non-verbal analogical reasoning); RVRT-2 = Revised Verbal Analogical Reasoning Task (verbal analogical reasoning - dichotomous); HSP ST/V = step-by-step/ visualisation heuristic strategy preference; HSP FP/C = free production/ combining heuristic strategy preference; HSP ANL = analogy heuristic preference; GNDR = gender; TSCHL = type of schooling

As shown in Table 6.36, the multicollinearity indicators fell within the specified ranges and this was supported by the standard error estimates for the independent variables (shown in Table K.4 in Appendix K), all of which were less than two (Allison, 1999; IDRE, 2016; Lomax & Hahs-Vaughn, 2012; Schwab, 2002). Table 6.36 also indicates that step-by-step/visualisation preference ($\chi^2_2 = 6.73$; $p = .035$), verbal analogical reasoning ($\chi^2_2 = 8.07$; $p = .018$), and gender ($\chi^2_2 = 13.33$; $p = .001$) were the only independent variables that acted as significant predictors of directed transfer. Table K.4 in Appendix K presents the significance and odds-ratios for each individual continuous independent variable and each individual level of the categorical independent variables (Huck, 2008; IDRE, 2016). Gender was significant for distinguishing both partial ($\chi^2_1 = 4.94$; $p = .026$; $OR = 0.605$) and full ($\chi^2_1 = 12.71$; $p = .000$; $OR = 0.408$) analogical solvers from non-analogical solvers; male participants were less likely to be in either the partial or the full analogical solution groups. Step-by-step/visualisation preference was only significant for distinguishing between full analogical and non-analogical solvers ($\chi^2_1 = 6.11$; $p = .013$; $OR = 0.920$); participants with higher step-by-step/visualisation preference scores were less likely to be in the full analogical solution group. Verbal analogical reasoning was also only significant for distinguishing between full analogical solvers and non-analogical solvers ($\chi^2_1 = 7.99$; $p = .005$; $OR = 0.526$); participants with lower verbal analogical reasoning scores were less likely to be in the full analogical solution group.

6.15.3. Predicting directed transfer with socioeconomic status as a predictor.

The third regression model for directed transfer included socioeconomic status as one of the predictors (independent variables). As shown in Table K.5 in Appendix K, the number of valid cases in this analysis was 601. The ratio of cases to independent variables was 85.9:1 (601:7) which was good (Hosmer & Lemeshow, 2000; Schwab, 2002). As shown in Table 6.37, the result of the likelihood ratio test for the model indicated that the full model acted as a significantly better predictor of directed transfer than the intercept-only model ($\chi^2_{16} = 49.30$; $p = .000$). The result of the Pearson ($\chi^2_{1184} = 1201.42$; $p = .356$) goodness-of-fit test was also non-significant, which suggested that the data fitted the model well. The deviance ($\chi^2_{1184} = 1266.76$; $p = .047$) goodness-of-fit test, however, was significant suggesting the data did not fit the model well. The pseudo r-squared measures were .079 for Cox and Snell; .089 for Nagelkerke; and .037 for McFadden (LAERD, 2016; Peng & So, 2002; Schwab, 2002).

Table 6.37

Main phase: Likelihood ratio test for model fit – directed transfer model three (socioeconomic status)

Model	Model Fitting Criteria	Likelihood Ratio Tests		
		χ^2	df	p
Directed transfer	-2 Log Likelihood			
Intercept only	1316.062			
Final	1266.761	49.300	16	.000

Table 6.38

Main phase: Predicted classification accuracy – directed transfer model three (socioeconomic status)

Directed transfer	Classification			% Correct
	0	1	2	
Observed				
0	72	79	37	38.3
1	56	104	65	46.2
2	32	79	77	41.0
Overall %	26.6	43.6	29.8	42.1

Table 6.39

Main phase: Predictors for directed transfer model three (socioeconomic status)

Effect Directed T.	Model Fitting	Likelihood Ratio Tests			Collinearity		
	Criteria	χ^2	df	p	Tol.	VIF	C.I.
	-2 Log Likelihood						
Intercept	1266.761	0.000	0	.	.	.	1.000
RAPM	1270.463	3.701	2	.157	0.921	1.086	8.090
HSP ST/V	1276.142	9.381	2	.009	0.782	1.279	9.126
HSP FP/C	1268.459	1.697	2	.428	0.808	1.237	10.794
HSP ANL	1267.163	0.401	2	.818	0.877	1.140	11.329
RVRT-2	1274.385	7.623	2	.022	0.899	1.113	15.055
GNDR	1279.929	13.168	2	.001	0.976	1.024	17.581
SES	1275.816	9.055	4	.060	0.959	1.043	27.525

RAPM = Raven's Advanced Progressive Matrices (non-verbal analogical reasoning); RVRT-2 = Revised Verbal Analogical Reasoning Task (verbal analogical reasoning - dichotomous); HSP ST/V = step-by-step/ visualisation heuristic strategy preference; HSP FP/C = free production/ combining heuristic strategy preference; HSP ANL = analogy heuristic preference; GNDR = gender; SES = socioeconomic status

The proportional by-chance-accuracy-rate was 33.6%; the minimum cut-off for a twenty-five percent or more improvement was thus 42%. As shown in Table 6.38, the predicted classification accuracy rate was also 42%, thus the model could be regarded as useful (Hosmer & Lemeshow, 2000; Schwab, 2002).

As shown in Table 6.39, the multicollinearity indicators fell within the specified ranges and this was supported by the standard error estimates for the independent variables (shown in Table K.6 in Appendix K), all of which were less than two (Allison, 1999; IDRE, 2016; Lomax & Hahs-Vaughn, 2012; Schwab, 2002). Table 6.39 also indicates that step-by-step/visualisation preference ($\chi^2_2 = 9.38$; $p = .009$), verbal analogical reasoning ($\chi^2_2 = 7.62$; $p = .022$), and gender ($\chi^2_2 = 13.17$; $p = .001$) were the only independent variables that acted as significant predictors of directed transfer. Table K.6 in Appendix K presents the significance and odds-ratios for each individual continuous independent variable and each individual level of the categorical independent variables (Huck, 2008; IDRE, 2016). Step-by-step/visualisation preference was significant for distinguishing both partial ($\chi^2_1 = 5.51$; $p = .019$; $OR = 0.928$) and full ($\chi^2_1 = 8.28$; $p = .004$; $OR = 0.908$) analogical solvers from non-analogical solvers; participants with higher step-by-step/visualisation preference scores were less likely to be in either the partial or full analogical solution groups. Gender was also significant for distinguishing both partial ($\chi^2_1 = 4.83$; $p = .028$; $OR = 0.612$) and full ($\chi^2_1 =$

12.55; $p = .000$; $OR = 0.409$) analogical solvers from non-analogical solvers; male participants were less likely to be in either the partial or full analogical solution groups. Verbal analogical reasoning was only significant for distinguishing between full analogical solvers and non-analogical solvers ($\chi^2_1 = 7.55$; $p = .006$; $OR = 0.535$); participants with lower verbal analogical reasoning scores were less likely to be in the full analogical solution group. Although only variables that act as significant predictors overall should be considered (Schwab, 2002), it is worth noting that one level of socioeconomic status was significant for distinguishing between full analogical solvers and non-analogical solvers ($\chi^2_1 = 5.74$; $p = .017$; $OR = 0.523$); participants categorised as being in the low socioeconomic status group were less likely to be in the full analogical solution group. Despite this, socioeconomic status was not a significant overall predictor of directed transfer in the model.

6.16. Main phase: Predicting open transfer

In order to establish the extent to which verbal and non-verbal analogical reasoning, analogy preference, step-by-step/visualisation preference, free production/combining preference, gender, and one of home language, type of schooling, and socioeconomic status could be used to predict open analogical problem solving, three binomial logistic regressions were run (Hosmer & Lemeshow, 2000; Howell, 2013; Huck, 2008).

6.16.1. Predicting open transfer with home language as a predictor.

The first regression model for open transfer included home language as one of the predictors (independent variables). As shown in Table K.7 in Appendix K, the number of valid cases in this analysis was 588. The ratio of cases to independent variables was 84:1 (588:7) which was good (Hosmer & Lemeshow, 2000; Schwab, 2002).

As shown in Table 6.40, the result of the likelihood ratio test for the model indicated that the full model acted as a significantly better predictor of open transfer than the intercept-only model ($\chi^2_7 = 36.75$; $p = .000$). The result of the Pearson ($\chi^2_{577} = 589.03$; $p = .355$) goodness-of-fit test was also non-significant, which suggested that the data fitted the model well. The deviance ($\chi^2_{577} = 703.44$; $p = .000$) goodness-of-fit test, however, was significant suggesting the data did not fit the model well. The pseudo r-squared measures were .061 for Cox and Snell; .084 for Nagelkerke; and .049 for McFadden (LAERD, 2016; Peng & So, 2002; Schwab, 2002).

Table 6.40

Main phase: Likelihood ratio test for model fit – open transfer model one (home language)

Model	Model Fitting Criteria		Likelihood Ratio Tests	
	-2 Log Likelihood	χ^2	df	p
Open transfer	742.965			
Intercept only	706.215	36.750	7	.000
Final				

Table 6.41

Main phase: Predicted classification accuracy – open transfer model one (home language)

Classification			
Open transfer	Predicted		
Observed	0	1	% Correct
0	370	24	93.9
1	166	28	14.4
Overall %	91.2	8.8	67.7

The proportional by-chance-accuracy-rate was 55.8%; the minimum cut-off for a twenty-five percent or more improvement was thus 70%. As shown in Table 6.41, the predicted classification accuracy rate was 68%, thus the model fell very slightly below the twenty-five percent improvement cut-off and, although still representing a substantial improvement over chance, was not as useful for prediction as would be ideal (Hosmer & Lemeshow, 2000; Schwab, 2002).

As shown in Table 6.42, the multicollinearity indicators fell within the specified ranges and this was supported by the standard error estimates for the independent variables (shown in Table K.8 in Appendix K), all of which were less than two (Allison, 1999; IDRE, 2016; Lomax & Hahs-Vaughn, 2012; Schwab, 2002). Table 6.42 also indicates that verbal analogical reasoning ($\chi^2_1 = 10.84$; $p = .001$) and home language ($\chi^2_1 = 6.29$; $p = .012$) were the only independent variables that acted as significant predictors of open transfer.

Table K.8 in Appendix K presents the significance and odds-ratios for each individual continuous independent variable and each individual level of the categorical independent variables (Huck, 2008; IDRE, 2016). Verbal analogical reasoning was significant for distinguishing between analogical solvers and non-analogical solvers ($\chi^2_1 = 10.77$; $p = .001$; $OR = 0.530$); participants with lower verbal analogical reasoning scores were less likely to

be in the analogical solution group. Home language was also significant for distinguishing between analogical solvers and non-analogical solvers ($\chi^2_1 = 6.20$; $p = .013$; $OR = 1.645$); English home language speakers were more likely to be in the analogical solution group.

Table 6.42

Main phase: Predictors for open transfer model one (home language)

Effect Open T.	Model Fitting	Likelihood Ratio Tests			Collinearity		
	Criteria	χ^2	df	p	Tol.	VIF	C.I.
Intercept	706.215	0.000	0	.	.	.	1.000
RAPM	709.427	3.213	1	.073	0.917	1.090	7.058
HSP ST/V	706.372	0.157	1	.692	0.782	1.278	10.338
HSP FP/C	706.387	0.172	1	.678	0.800	1.250	10.795
HSP ANL	708.393	2.178	1	.140	0.878	1.139	11.148
RVRT-2	717.058	10.843	1	.001	0.859	1.164	15.092
GNDR	706.429	0.215	1	.643	0.986	1.014	17.725
HLANG	712.502	6.287	1	.012	0.884	1.131	28.020

RAPM = Raven's Advanced Progressive Matrices (non-verbal analogical reasoning); RVRT-2 = Revised Verbal Analogical Reasoning Task (verbal analogical reasoning - dichotomous); HSP ST/V = step-by-step/ visualisation heuristic strategy preference; HSP FP/C = free production/ combining heuristic strategy preference; HSP ANL = analogy heuristic preference; GNDR = gender; HLANG = home language

6.16.2. Predicting open transfer with type of schooling as a predictor.

The second regression model for open transfer included type of schooling as one of the predictors (independent variables). As shown in Table K.9 in Appendix K, the number of valid cases in this analysis was 572. The ratio of cases to independent variables was 81.7:1 (572:7) which was good (Hosmer & Lemeshow, 2000; Schwab, 2002).

As shown in Table 6.43, the result of the likelihood ratio test for the model indicated that the full model acted as a significantly better predictor of open transfer than the intercept-only model ($\chi^2_7 = 50.63$; $p = .000$). The result of the Pearson ($\chi^2_{561} = 568.73$; $p = .401$) goodness-of-fit test was also non-significant, which suggested that the data fitted the model well. The deviance ($\chi^2_{561} = 671.07$; $p = .001$) goodness-of-fit test, however, was significant suggesting the data did not fit the model well. The pseudo r-squared measures were .085 for Cox and Snell; .118 for Nagelkerke; and .070 for McFadden (LAERD, 2016; Peng & So, 2002; Schwab, 2002).

Table 6.43

Main phase: Likelihood ratio test for model fit – open transfer model two (type of schooling)

Model	Model Fitting Criteria		Likelihood Ratio Tests	
	-2 Log Likelihood	χ^2	df	p
Open transfer				
Intercept only	724.472			
Final	673.844	50.628	7	.000

Table 6.44

Main phase: Predicted classification accuracy – open transfer model two (type of schooling)

Classification			
Open transfer	Predicted		
Observed	0	1	% Correct
0	342	40	89.5
1	135	55	28.9
Overall %	83.4	16.6	69.4

The proportional by-chance-accuracy-rate was 55.6%; the minimum cut-off for a twenty-five percent or more improvement was thus 70%. As shown in Table 6.44, the predicted classification accuracy rate was 69%, thus the model fell very slightly below the twenty-five percent improvement cut-off and, although still representing a substantial improvement over chance, was not as useful for prediction as would be ideal (Hosmer & Lemeshow, 2000; Schwab, 2002).

As shown in Table 6.45, the multicollinearity indicators fell within the specified ranges and this was supported by the standard error estimates for the independent variables (shown in Table K.10 in Appendix K), all of which were less than two (Allison, 1999; IDRE, 2016; Lomax & Hahs-Vaughn, 2012; Schwab, 2002). Table 6.45 also indicates that verbal analogical reasoning ($\chi^2_1 = 12.58$; $p = .000$) and type of schooling ($\chi^2_1 = 19.13$; $p = .000$) were the only independent variables that acted as significant predictors of open transfer.

Table K.10 in Appendix K presents the significance and odds-ratios for each individual continuous independent variable and each individual level of the categorical independent variables (Huck, 2008; IDRE, 2016). Verbal analogical reasoning was significant for distinguishing between analogical solvers and non-analogical solvers ($\chi^2_1 = 12.48$; $p = .000$; $OR = 0.505$); participants with lower verbal analogical reasoning scores were less likely to

be in the analogical solution group. Type of schooling was also significant for distinguishing between analogical solvers and non-analogical solvers ($\chi^2_1 = 18.81$; $p = .000$; $OR = 0.443$); participants from government school backgrounds were less likely to be in the analogical solution group.

Table 6.45

Main phase: Predictors for open transfer model two (type of schooling)

Effect Open T.	Model Fitting	Likelihood Ratio Tests			Collinearity		
	Criteria	χ^2	df	p	Tol.	VIF	C.I.
Intercept	673.844	0.000	0	.	.	.	1.000
RAPM	677.623	3.779	1	.052	0.933	1.071	8.164
HSP ST/V	673.886	0.042	1	.837	0.780	1.283	8.975
HSP FP/C	674.061	0.218	1	.641	0.805	1.242	10.863
HSP ANL	675.499	1.655	1	.198	0.871	1.148	11.180
RVRT-2	686.426	12.582	1	.000	0.903	1.107	15.062
GNDR	674.498	0.654	1	.419	0.985	1.016	17.561
TSCHL	692.977	19.133	1	.000	0.973	1.028	27.673

RAPM = Raven's Advanced Progressive Matrices (non-verbal analogical reasoning); RVRT-2 = Revised Verbal Analogical Reasoning Task (verbal analogical reasoning - dichotomous); HSP ST/V = step-by-step/ visualisation heuristic strategy preference; HSP FP/C = free production/ combining heuristic strategy preference; HSP ANL = analogy heuristic preference; GNDR = gender; TSCHL = type of schooling

6.16.3. Predicting open transfer with socioeconomic status as a predictor.

The third regression model for open transfer included socioeconomic as one of the predictors (independent variables). As shown in Table K.11 in Appendix K, the number of valid cases in this analysis was 588. The ratio of cases to independent variables was 84:1 (588:7) which was good (Hosmer & Lemeshow, 2000; Schwab, 2002).

As shown in Table 6.46, the result of the likelihood ratio test for the model indicated that the full model acted as a significantly better predictor of open transfer than the intercept-only model ($\chi^2_8 = 41.13$; $p = .000$). The result of the Pearson ($\chi^2_{579} = 590.68$; $p = .359$) goodness-of-fit test was also non-significant, which suggested that the data fitted the model well. The deviance ($\chi^2_{579} = 704.61$; $p = .000$) goodness-of-fit test, however, was significant suggesting the data did not fit the model well. The pseudo r-squared measures were .068 for Cox and Snell; .094 for Nagelkerke; and .055 for McFadden (LAERD, 2016; Peng & So, 2002; Schwab, 2002).

Table 6.46

Main phase: Likelihood ratio test for model fit – open transfer model three (socioeconomic status)

Model	Model Fitting Criteria	Likelihood Ratio Tests		
		χ^2	df	p
Open transfer	-2 Log Likelihood			
Intercept only	745.737			
Final	704.607	41.130	8	.000

The proportional by-chance-accuracy-rate was 55.8%; the minimum cut-off for a twenty-five percent or more improvement was thus 70%. As shown in Table 6.47, the predicted classification accuracy rate was 69%, thus the model fell very slightly below the twenty-five percent improvement cut-off and, although still representing a substantial improvement over chance, was not as useful for prediction as would be ideal (Hosmer & Lemeshow, 2000; Schwab, 2002).

As shown in Table 6.48, the multicollinearity indicators fell within the specified ranges and this was supported by the standard error estimates for the independent variables (shown in Table K.12 in Appendix K), all of which were less than two (Allison, 1999; IDRE, 2016; Lomax & Hahs-Vaughn, 2012; Schwab, 2002). Table 6.48 also indicates that verbal analogical reasoning ($\chi^2_1 = 12.26$; $p = .000$) and socioeconomic status ($\chi^2_2 = 10.37$; $p = .006$) were the only independent variables that acted as significant predictors of open transfer.

Table K.12 in Appendix K presents the significance and odds-ratios for each individual continuous independent variable and each individual level of the categorical independent variables (Huck, 2008; IDRE, 2016). Verbal analogical reasoning was significant for distinguishing between analogical solvers and non-analogical solvers ($\chi^2_1 = 12.17$; $p = .000$; $OR = 0.514$); participants with lower verbal analogical reasoning scores were less likely to be in the analogical solution group. Low ($\chi^2_1 = 9.47$; $p = .002$; $OR = 0.449$) and average ($\chi^2_1 = 4.82$; $p = .028$; $OR = 0.619$) socioeconomic status were also significant for distinguishing between analogical solvers and non-analogical solvers; participants who were categorised in the low and average socioeconomic status groups were less likely to be in the analogical solution group.

Table 6.47

Main phase: Predicted classification accuracy – open transfer model three (socioeconomic status)

Classification			
Open transfer	Predicted		
Observed	0	1	% Correct
0	362	32	91.9
1	153	41	21.1
Overall %	87.6	12.4	68.5

Table 6.48

Main phase: Predictors for open transfer model three (socioeconomic status)

Effect	Model Fitting	Likelihood Ratio Tests			Collinearity		
Open T.	Criteria						
	-2 Log Likelihood	χ^2	df	p	Tol.	VIF	C.I.
Intercept	704.607	0.000	0	.	.	.	1.000
RAPM	707.672	3.065	1	.080	0.921	1.086	8.090
HSP ST/V	704.641	0.034	1	.853	0.782	1.279	9.126
HSP FP/C	704.848	0.241	1	.624	0.808	1.237	10.794
HSP ANL	706.366	1.758	1	.185	0.877	1.140	11.329
RVRT-2	716.869	12.262	1	.000	0.899	1.113	15.055
GNDR	705.210	0.603	1	.437	0.976	1.024	17.581
SES	714.976	10.369	2	.006	0.959	1.043	27.525

RAPM = Raven's Advanced Progressive Matrices (non-verbal analogical reasoning); RVRT-2 = Revised Verbal Analogical Reasoning Task (verbal analogical reasoning - dichotomous); HSP ST/V = step-by-step/ visualisation heuristic strategy preference; HSP FP/C = free production/ combining heuristic strategy preference; HSP ANL = analogy heuristic preference; GNDR = gender; SES = socioeconomic status

6.17. Main phase: Patterns in the prediction of directed and open analogical transfer

Certain patterns emerged across the results of the three regression models calculated to establish the extent to which the various independent variables acted as significant predictors of directed analogical transfer. In all three models, non-verbal analogical reasoning, analogy preference, and free production/ combining preference did not act as significant predictors. In contrast, both gender and step-by-step/ visualisation preference did act as significant predictors in all three models, although in one model step-by-step/ visualisation only distinguished between non-analogical and full analogical solvers (in all other cases, these predictors distinguished both partial and full analogical solvers from

non-analogical solvers). For gender, male participants were consistently less likely to be in the partial and full analogical solution groups; and for step-by-step/visualisation preference, those with a higher preference for this strategy cluster were consistently less likely to be in the full analogical solution group and, for two of the three models, in the partial analogical solution group.

For two of the models (type of schooling and socioeconomic status), verbal analogical reasoning acted as a significant predictor of directed transfer. In both cases participants with lower verbal analogical reasoning scores were less likely to be in the full analogical solution group (no distinction was made for partial analogical solvers for this variable). Interestingly, for the third model (home language), verbal analogical reasoning fell away as a significant predictor. Although multicollinearity was not problematic for the models generally, this may have been due to the inclusion of home language as a predictor in the model – the two variables related significantly to one another although the Phi coefficient ($\chi^2_1 = 54.77; p = .000; \phi = -.289; p = .000$) was relatively weak. It is thus possible that because home language acted as a significant predictor in this model it masked the potential predictive power of verbal analogical reasoning due to shared variance (Allison, 1999; Hosmer & Lemeshow, 2000; Huck, 2008; Mason & Perreault, 1991). For home language, those participants who spoke English as a home language were more likely to be in the full analogical solution group (no distinction was made for partial analogical solvers for this variable). Neither type of schooling nor socioeconomic status acted as significant predictors of directed transfer, although one level of socioeconomic status (low socioeconomic status) did distinguish between non-analogical and full analogical solvers.

Certain patterns also emerged across the results of the three regression models calculated to establish the extent to which the various independent variables acted as significant predictors of open analogical transfer. In all three models, non-verbal analogical reasoning, analogy preference, step-by-step/visualisation preference, free production/combining preference, and gender did not act as significant predictors. In contrast, verbal analogical reasoning did act as a significant predictor in all three models; those participants with lower verbal analogical reasoning scores were consistently less likely to be in the analogical solution group. Home language, type of schooling, and socioeconomic status also acted as significant predictors of open transfer across the three models. English home language speakers were more likely to be in the analogical solution group, and participants from government school backgrounds or those who were categorised as being in either the low or average socioeconomic groups were less likely to be in the analogical solution group.

Across all of the models, only verbal analogical reasoning and home language acted as fairly consistent predictors of analogical transfer performance. Non-verbal analogical reasoning, analogy preference, and free production/combining preference also consistently did not predict analogical transfer across any of the models. Step-by-step/visualisation preference and gender predicted directed transfer, but not open transfer; and type of schooling and socioeconomic status predicted open transfer but not directed transfer.

6.18. Conclusion

This chapter has described the results of the analyses conducted to address the seven primary research questions posed in the study (please refer to Appendix L for a graphic representation of the key relationships explored in the study), as well as the findings from the pilot phase and preliminary analyses in the main study that were necessary to establish the groundwork for the primary analyses. Key findings that emerged included:

- a) A significant, positive association between rates of directed and open analogical transfer in the sample.
- b) A general pattern indicating that participants who presented analogical solutions for both the directed and open transfer tasks exhibited higher levels of verbal and non-verbal analogical reasoning skill, although the effect sizes for this were small.
- c) No significant association between analogical problem solving and analogy as a preferred heuristic strategy for either analogical transfer task.
- d) Significantly lower rates of directed analogical transfer for those with a higher self-reported preference for step-by-step/visualisation-based heuristic strategies.
- e) Significant associations between directed analogical transfer performance and gender, home language, and socioeconomic status in the sample as well as significant associations between open analogical transfer and home language, socioeconomic status, and type of schooling in the sample.
- f) Step-by-step/ visualisation heuristic strategy preference, gender, verbal analogical reasoning, and home language as significant predictors of directed analogical transfer performance in the sample.
- g) Verbal analogical reasoning, home language, type of schooling, and socioeconomic status as significant predictors of open analogical transfer performance in the sample.

The following chapter will present a discussion of these findings and the other results identified, as well as the potential implications thereof, conclusions, strengths and limitations, and possible directions for future research.

Chapter 7: Discussion

The current study aimed to contribute to existing work in the field of analogical problem solving by offering a small yet original set of findings as a base for extending and refining conceptual understandings and enhancing application. More specifically, the focus of the study was to explore the role played by several individual difference factors in determining analogical transfer in a unique and novel context. To this end, the study employed two different methods to assess analogical problem solving performance (directed and open analogical transfer); the associations between both of these and verbal analogical reasoning, non-verbal analogical reasoning, heuristic strategy preference (including a preference for analogy as a heuristic strategy), and a number of demographic variables (gender, home language, socioeconomic status, and type of schooling) were then examined (please refer to Appendix L for a graphic representation of the key relationships explored in the study). Predictive models incorporating these variables with analogical transfer as the outcome were also created.

In the sections that follow, a discussion is presented of the ways in which the research questions posed above were addressed and the results that emerged. These findings are contextualised in terms of the existing literature, and their potential theoretical and practical contribution outlined. This is followed by an overview of the key implications of the study as well as its potential contribution to knowledge; a critical analysis of the limitations of the study, and possible directions for future research.

7.1. Question one: Rate of directed analogical transfer

The first research question posed in the study was to identify the rate of directed analogical transfer that occurred between a given source analogue and an isomorphic target problem in the sample of South African university students that was obtained. The source analogue that was provided amalgamated two relatively common variations of the convergence schema - the general and the fire chief (Gick & Holyoak, 1980; 1983) - into a single story followed by a comprehension exercise; and the target analogue was a third, lesser known variation – the aquarium (Catrambone & Holyoak, 1989) – which was presented as an independent, creative problem solving exercise (please refer to Appendix F). For the main study, the instructions for the target included a general hint advising students that they might find it useful to consider the source story when attempting to complete the target exercise.

When the task was initially presented during the pilot study, the hint in the instructions was excluded, as the original intention was to assess rates of spontaneous analogical transfer in the sample. The feasibility of this was particularly important to consider during the piloting phase as rates of spontaneous analogical problem solving in experimental settings have traditionally been very low, ranging between ten and forty percent on average (Anolli et al., 2001; Catrambone & Holyoak, 1989; Gick & Holyoak, 1980; 1983; Kubricht et al., 2015; 2017; Monaghan et al., 2015; Novick & Holyoak, 1991; Reeves & Weisberg, 1994). It was hoped that the use of several strategies previously shown to enhance the extraction of a shared relational structure and aid schema formation would increase rates of spontaneous transfer in the study, thus ensuring a viable sample size. These strategies included: the provision of multiple source exemplars; embedding one exemplar of the underlying schematic principle within the other in the source story to hint at analogical solution; and the inclusion of four comprehension questions designed to highlight key aspects of the shared solution strategy and thus encourage both comparison and retrieval practice (Antonietti, 1996; Bearman et al., 2002; Catrambone & Holyoak, 1989; Edwards et al., 2014; Gentner & Colhoun, 2010; Gick & Holyoak, 1983; Hostetter et al., 2018; Kubricht et al., 2015; 2017; Kurtz & Loewenstein, 2007; Novick & Holyoak, 1991; Peterson & Wissman, 2018; Reeves & Weisberg, 1984; Richland & McDonough, 2010).

Analysis of the results obtained from the pilot study clearly showed that despite these steps, the rate of spontaneous transfer remained very low. Although the pilot participants ($n = 43$) averaged four distinct solutions for lighting the aquarium and most participants gave between two and five solutions, the vast majority of these were either non-analogical (thirty-five percent) or partially analogical (forty-nine percent), representing no more than two of the four elements of the convergence schema and missing the core solution aspects of circular disposition around the target and simultaneous application of the force (Antonietti & Gioietta, 1995; Catrambone et al., 2006; Catrambone & Holyoak, 1989; Cushen, 2012; Cushen & Wiley, 2018; Gick & Holyoak, 1980; 1983; Kubricht et al., 2015; 2017; Novick & Holyoak, 1991; Peterson & Wissman, 2018). Ultimately only sixteen percent of the pilot sample ($n = 7$) provided solutions that were classified as fully analogical.

This very low rate of spontaneous analogical transfer, although disappointing, does align with previous findings regarding the high level of difficulty of spontaneous inter-domain analogical problem solving, and supports suggestions that recognition of the source as relevant to the solution of the target without explicit instruction may be particularly difficult (Anolli et al., 2001; Bearman et al., 2002; Catrambone & Holyoak, 1989; Cushen & Wiley, 2018; Francis, 1999; George & Wiley, 2018; Kubricht et al., 2015; 2017; Markman et al.,

2007; Mason & Tornatora, 2016; Monaghan et al., 2015; Novick & Holyoak, 1991; Reeves & Weisberg, 1994; Richland & McDonough, 2010). It is, however, interesting to note that the provision of two source analogues, a mechanism for retrieval practice, and an implied hint regarding adaptation of the solution strategy within the source story structure failed to ameliorate this, despite previous research suggesting this would be the case (Catrambone & Holyoak, 1989; Chen & Mo, 2004; Edwards et al., 2014; Gick & Holyoak, 1983; Gick & Paterson, 1992; Hostetter et al., 2018; Novick & Holyoak, 1991; Peterson & Wissman, 2018; Reeves & Weisberg, 1994; Richland & McDonough, 2010). One possibility, reflecting a methodological weakness of the study, may be that participants in the pilot study simply did not read the source story prior to attempting the target problem, as order of completion for the tasks was not strictly controlled. Another possibility, linked to both transparency and concreteness, is that the high level of detail in the source story may have obscured, and thus made it difficult to extract, the key structural relations present between the sources and the target (Clement, 1994; Day & Goldstone, 2012; Kubricht et al., 2017; Neuman & Schwarz, 1998; Reeves & Weisberg, 1994; Richland & McDonough, 2010). The lack of surface similarity and degree of distance between the various domains within which the three analogues were based may have further exacerbated this (Barnett & Ceci, 2002; Bassok, 2003; Blanchette, 2000; Catrambone & Holyoak, 1989; Corkill & Fager, 1995; Francis, 1999; Gentner & Colhoun, 2010; Gentner & Smith, 2012; 2013; Ozkan & Dogan, 2012; Reeves & Weisberg, 1994; Thomas, 2008; Zook, 1991). These possibilities align with previous discussions regarding reasons for difficulties associated with cross-domain spontaneous analogical problem solving, and thus both confirm and extend existing theory within a novel sample group and context.

Although anticipated to an extent, the very low rate of full spontaneous analogical transfer obtained also suggested that if the task were carried through in its original form to the main study, the number of cases of analogical problem solving identified might not be sufficient to permit the aims of the study to be achieved. As a result, a decision was taken to alter the task through inclusion of the general hint, thus shifting the task from one assessing spontaneous analogical transfer to one assessing directed analogical transfer (Anolli et al., 2001; Corkill & Fager, 1995; Cushen, 2012; Gick & Holyoak, 1983; Kubricht et al., 2017; Ormerod & MacGregor, 2017; Richland & McDonough, 2010). It was hoped that this alteration would increase the number of cases of full analogical transfer in the sample, thus providing a sufficient sample size to meet the requirements for running the proposed analyses and addressing the intended research questions in the study.

Within the main study, the average number of solutions provided by participants ($n = 608$) was also four, with most participants providing between two and four separate solution strategies. Although sixteen percent of the sample identified at least one strategy that could be classified as 'reduced intensity', and twenty-two percent identified at least one strategy that could be categorised as 'using multiple lights', thus representing partial analogical solutions; only twenty-six percent of participants provided a strategy that could be classified as representing circular disposition around the object, and only five percent provided a strategy representing simultaneous application of the force (light). Thus thirty-one percent ($n = 190$) of participants provided only non-analogical solutions, thirty-eight percent ($n = 229$) provided partially analogical solutions, and thirty-one percent ($n = 189$) provided fully analogical solutions.

Although considerably higher than the rate of spontaneous transfer observed in the pilot study, it is important to note that the rate of full directed analogical transfer observed in the sample was still lower than that typically seen in international studies, particularly when the provision of two source analogues is factored in (Catrambone & Holyoak, 1989; Corkill & Fager, 1999; George & Wiley, 2018; Gick & Holyoak, 1993; Kubricht et al., 2017; Pedone et al., 2001; Speicher & Kehrhahn, 2009). For example, Gick and Holyoak (1983) experimented with the provision of two source exemplars based on the convergence schema and incorporated level of similarity between the source exemplars as another factor. In their 'similar analogues' condition, a total of seventy-eight percent of participants provided a fully analogical solution to the target; thirty-nine percent spontaneously and an additional thirty-nine percent following a non-specific hint. In their 'dissimilar analogues' condition, a total of eighty-three percent of participants produced a fully analogical solution to the target; fifty-two percent spontaneously and an additional thirty-one percent following provision of a non-specific hint (Gick & Holyoak, 1983). Catrambone and Holyoak (1989) also presented participants with two source analogues in one of their studies, following which half the participants completed an additional comparison exercise. Half the participants then completed the target analogue after a thirty minute intervention (both without and then with a hint as to the relevance of the sources given) and the other half completed the target exercise after a one week delay (Catrambone & Holyoak, 1989). In the 'thirty minute delay' condition, a total of seventy-one percent of participants in the comparison condition and fifty-eight percent of participants in the non-comparison condition gave fully analogical solutions (including those who produced the solution spontaneously – eleven percent and ten percent respectively). In the 'one-week delay condition', a total of forty-seven percent of participants in the comparison condition and thirty-eight participants in the non-comparison condition produced fully analogical solutions (including those who produced the solution

spontaneously – seven percent and six percent respectively) (Catrambone & Holyoak, 1989).

Similar rates of directed transfer (also termed prompted or assisted transfer) have been observed in other studies; for example, Cushen (2012) noted transfer rates of forty-two percent and sixty-one percent respectively for a convergence schema target following provision of two source analogues and prompting without and with an explicit comparison task. Corkill and Fager (1995) identified rates of directed transfer ranging between twenty-nine and forty-seven percent for different pairs of convergence schema analogues, however in their study participants were provided with only a single source analogue. Fukumine and Kennison (2016) also utilised only a single source analogue representing the convergence schema; fifty-four percent of their participants solved the target spontaneously and an additional sixteen percent solved the target once a hint was provided. These rates were similar to those observed by Kubricht et al. (2017), who identified total convergence schema transfer rates of eighty-three percent, sixty-nine percent, and eighty-eight percent across the different conditions in their study – rates of spontaneous transfer in these groups were fifty-five, fifty, and eighty-three percent respectively. Kubricht et al. (2017) also noted that “... *this level of overall performance is consistent with previous findings showing that roughly 80% of college students are able to solve the radiation problem following a hint to think back to a relevant source analog...*” (p.580). George and Wiley (2018) suggest that the average rate of directed (hinted) transfer across multiple studies is sixty-five percent. Taken together, these findings support a trend of far higher rates of directed transfer in international samples than the rate observed in the current study.

It is worth noting, however, that in all of the studies cited above, administration of the source and target analogues was carried out under strictly controlled experimental conditions that included a form of repeated measurement, specifically an initial attempt to solve the target spontaneously before a hint was provided and directed and total transfer assessed. In contrast, in the current study participants were free to complete the tasks over an extended time period and only attempted to solve the target once following provision of a general hint regarding relevance of the source. It is, therefore, possible that the higher rates of directed transfer observed in the international studies may be an artefact of the particular method of investigation applied; for example, the purpose of providing the source may have been more obviously apparent or the strict sequencing of the tasks may have induced changes in participants' effort, motivational state, affect, and focus across consecutive attempts that inflated the rates of analogical solving achieved (cf. Holyoak, 2012; Reeves & Weisberg, 1994; Spencer & Weisberg, 1986). This proposition, although fairly likely, can be

refuted to an extent by the findings obtained by Anolli et al. (2001). As part of their investigation into explanations for low rates of spontaneous analogical problem solving, they implemented a between-subjects design comparing rates of spontaneous and directed analogical transfer of the convergence schema across different groups of participants (in contrast to the more common consecutive process implemented). Over seven experiments utilising multiple groups of participants, their findings consistently produced rates of analogical transfer ranging between fifty and seventy percent when participants were provided with a hint regarding the relevance of the source (Anolli et al., 2001). Although limited to a single research series, these results do seem to provide a broader base for arguing that the rate of directed transfer observed in the current study is lower than rates typically observed in international studies, although potentially critical methodological differences must be kept in mind.

Other reasons for the difference that was observed are unclear, although it does seem unlikely that the issue regarding order of completion highlighted in the pilot study would have applied in the main study. The reason for this is that the general hint given in the instructions would have alerted participants to the potential utility of completing the comprehension exercise before attempting or finalising responses to the creative problem solving task of lighting the aquarium. In addition, a brief analysis of the answers provided to the comprehension questions by participants in the main study served as an important verification that the source passage had been read and understood in basic terms. It is, however, possible that participants did not read the instructions that included the hint when attempting to solve the target problem or chose to ignore the suggestion to consider the source story. If so, this could explain why the rate of directed transfer observed was closer in range to rates of spontaneous transfer observed in international studies under experimental conditions (Anolli et al., 2001; Antonietti, 1996; Bassok, 2003; Catrambone & Holyoak, 1989; Catrambone et al., 2006; Corkill & Fager, 1995; Cushen, 2012; Edwards et al., 2014; Gick & Holyoak, 1980; 1983; Kubricht et al., 2015; Novick & Holyoak, 1991; Pedone et al., 2001).

It also seems very unlikely that one of the most common explanations for inter-domain transfer difficulty - retrieval failure resulting from a lack of awareness of the relevance of the source for the target - would apply in this instance, as the non-directive hint would have alerted participants to the potential importance of the source story (Anolli et al., 2001; Gentner & Colhoun, 2010; Gentner et al., 2003; Holyoak, 2012; Kostic et al., 2010; Kubricht et al., 2015; Kurtz & Loewenstein, 2007; Trench et al., 2016; Zook, 1991). A critical implication of this is that any impediment to a successful (i.e. analogical) resolution of the target in this study is likely to have occurred at a later stage of the analogical solution

process, either as a result of a failure to map some or all of the relevant structural similarities shared between the analogues or as a result of difficulties in adapting the solution strategy (Bassok, 2003; Gentner & Smith, 2012; 2013; Novick & Holyoak, 1991; Thomas, 2008; Zook, 1991). Although mapping has typically been regarded as an 'easier' process to enact than retrieval (cf. Gentner & Smith, 2012; 2013; Holyoak, 2012), it still appears to be influenced by a number of factors, including internal characteristics such as surface and structural similarity, transparency, and pragmatic centrality; individual differences such as expertise, age, and motivation; and task characteristics such as complexity and processing load, context, and time constraints (Bassok, 2003; Cushen & Wiley, 2018; Gentner & Smith, 2012; 2013; Gick & Holyoak, 1980; Holyoak, 2012; Keane, 1996; Kokinov & Petrov, 2000; Krawczyk et al., 2004; Lee, 1992; Novick & Holyoak, 1991; Yanowitz, 2001). Furthermore, it is important to note that even if mapping is enacted successfully, this does not automatically imply that an appropriate adaptation of the solution will follow; adaptation is also affected by a number of the same concerns, including pragmatic constraints, individual differences, and surface similarity (Holyoak, 2012; Keane, 1996; Novick & Holyoak, 1991; Schelhorn et al., 2007). There are, therefore, a number of interesting possibilities that could explain the low rate of observed directed transfer in the current study, although establishing which of these was directly applicable is not possible.

One viable factor that may have contributed to difficulties in recognising and extracting the relevant shared structural features between the analogues could have been their location in widely variant content domains (Barnett & Ceci, 2002; Chai et al., 2015; Corkill & Fager, 1995; Cushen, 2012; Day & Goldstone, 2012; Holyoak, 2012; Klavir & Gorodetsky, 2011; Lee, 1992; Ozkan & Dogan, 2012; Thomas, 2008). Although this reduced the degree of surface similarity between the objects in each analogue (a situation thought to encourage a focus on integrative processing rather than attribute similarity), the lack of corresponding relations shared between surface-similar elements may have also made it harder to successfully extract core structural elements from each exemplar (Bassok, 2003; Day & Goldstone, 2012; Gentner & Smith, 2012; 2013; Krawczyk et al., 2004; Ormerod & MacGregor, 2017; Reeves & Weisberg, 2004; Thomas, 2008). This aligns with literature suggesting that corresponding surface similarities are typically easier to identify than corresponding structural relations, and the former are thus often employed as a method of identification or cue for the latter (Bassok, 2003; Blanchette, 2000; Catrambone & Holyoak, 1989; Chen & Siegler, 2013; Cushen & Wiley, 2018; Day & Goldstone, 2012; Francis, 1999; Gentner & Colhoun, 2010; Gentner & Smith, 2012; Kaminski et al., 2013; Reeves & Weisberg, 1994; Richland & McDonough, 2010; Thomas, 2008; Trench & Minervino, 2015; Zook, 1991). The mapping process between the analogues may have also been affected by

the extent to which the participants had previous knowledge of and experience in each of the content domains, as well as with the particular scenarios depicted in each analogue (Antonietti & Gioletta, 1995; Billing, 2007; Corkill & Fager, 1995; Jonassen, 2000; Lee, 1992; Zook, 1991). Zook (1991) notes that this effect is bi-directional – specifically, failures to identify correspondences may occur as a result of “*deficiencies in base domain knowledge*” (p. 58); however “*excessive base domain knowledge*” (p.59) can also impede the transfer process if participants use this to frame inferences that are excessive or inaccurate. This implies that if key concepts in the analogues (for example, ‘aquarium’, ‘fire’, ‘general’, and so forth...) had either not been previously encountered by participants or had been encountered in a manner that produced an idiosyncratic framing, this could have interfered with participants’ capacity to map and adapt the solution strategy from the sources to the target successfully.

Another viable explanation for the low rate of successful analogical problem solving observed stems from the structuring of the two source analogues in the main study; these were presented to participants as an integrated story with one analogue (the fire chief) embedded in the second analogue (the general), rather than as two separate exemplars. Although intended as a mechanism to support transfer through modelling solution adaptation across contexts, this form of presentation was also very rich in descriptive detail and contained a fair bit of information that was not directly aligned with the underlying relational structure shared between the analogues. Thus the levels of concreteness and transparency in the integrated source story may have made it more difficult for participants to successfully distinguish between irrelevant surface features and critical relational elements, recognise and extract core structural relations between the analogues, separate causal antecedents and candidate inferences, or extend the solution strategy to the target analogue (Gentner & Smith, 2012; Holyoak, 2012; Kaminski et al., 2013; Kubricht et al., 2015; 2017; Ozkan & Dogan, 2012; Reeves & Weisberg, 1994). This proposition aligns with previous empirical findings suggesting that both increased semantic overlap between analogues and higher levels of perceptual richness within analogues can inhibit recognition of relational similarity and increase transfer difficulty (Catrambone et al., 2006; Day & Goldstone, 2012; Holyoak, 2012; Kaminski et al., 2013). As was the case for spontaneous transfer, the situation of the three exemplars in highly variant domains may have also further contributed to difficulties in identifying relevant structural relations shared between the analogues (Barnett & Ceci, 2002; Bassok, 2003; Blanchette, 2000; Catrambone & Holyoak, 1989; Corkill & Fager, 1995; Francis, 1999; Gentner & Colhoun, 2010; Gentner & Smith, 2012; 2013; Ozkan & Dogan, 2012; Reeves & Weisberg, 1994; Thomas, 2008; Zook, 1991).

Although speculative, these explanations could potentially account for the relatively lower rate of directed analogical problem solving observed in the current study. It is not, however, possible to gauge the extent to which this observed rate represents a genuine trend in differential performance between South African and international samples as a result of the methodology employed as well as a lack of comparable previous studies carried out in the South African context. A key direction for future research would thus be to establish rates of spontaneous and directed analogical transfer across different South African sample groups using variant analogues and methodological conditions as a basis for direct comparison with international findings.

7.2. Question two: Rate of open analogical transfer

The second research question posed in the study was to identify the rate of open analogical transfer that occurred between two problem isomorphs presented without a pre-conceived solution strategy in the sample of South African university students that was obtained. The term 'open analogical transfer' refers to a relatively novel approach to assessing analogical problem solving that was adapted and implemented in the current study. The rationale for this approach stemmed from critiques raised regarding the traditional two-stage experimental process utilised in a large number of previous studies i.e. controlled exposure to a solution strategy to be used as a source followed by an assessment of the extent to which adaptation of this given solution strategy was achieved for an isomorphic target problem (Antonietti, 1996; Barnett & Ceci, 2002; Bassok, 2003; Catrambone et al., 2006; Cushen & Wiley, 2018; Gick & Holyoak, 1980; 1983; Holyoak, 2012; Trench & Minervino, 2015; Zook, 1991). Although this process is efficient, practical, and allows for investigative control, its ability to adequately capture and represent the processes undertaken during real-world analogical problem solving has been questioned. Common concerns raised include: the degree of context proximity between the source and the target; the extent to which pre-determined solution strategies developed by the researcher are privileged as representative of transfer; and artificial restriction of the scope of source information participants are expected to draw on during the solution process (Anolli et al., 2001; Blanchette, 2000; Chen et al., 2004; Day & Goldstone, 2012; Gentner & Smith, 2012; Holyoak, 2012; Lave, 1998; Lee, 1992; Lobato, 2006; Nokes, 2009; Novick & Holyoak, 1991; Trench & Minervino, 2015).

In an attempt to address certain of these concerns, particularly those related to scope and privilege, the procedure used by Gick and Holyoak (1980) in their third experiment to explore transfer of self-developed solution strategies was adapted for the current study. Two

descriptions containing isomorphic problem situations without any given solution strategies were presented to the participants as independent creative problem solving exercises. The two analogues were sourced from Chen and Daehler (1989) – both reflected problem situations in which access to a desired resource was restricted by too narrow an entrance (in one instance, a thirsty bird unable to access water in a bottle; in the second instance, a group of boys unable to access a ping-pong ball trapped in a hole in the wall). These isomorphs were selected as they were situated in distinct content domains, depicted fairly familiar concepts, and were deemed to contain relatively accessible shared structural relations (Barnett & Ceci, 2002; Chen & Daehler, 1989).

In contrast to Gick and Holyoak (1980), participants were not given any hint that the solution of one of the analogues might be useful to solve the other or that the exercises were connected in any way; and there was also no specified order for attempting to solve the problems, although the order of task presentation in the questionnaire pack did make it more likely that the thirsty-bird analogue would be attempted first by participants. Participants were also free to draw on the full range of previous experiences available to them when attempting to solve either analogue; this was incorporated to better reflect real-world analogical solving as it plays out in naturalistic environments (cf. Bearman et al., 2002; Blanchette, 2000; Blanchette & Dunbar, 2002; Day & Goldstone, 2012; Holyoak, 2012; Lee, 1992; Trench & Minervino, 2015). The most vital distinction between previous work (cf. Chen & Daehler, 1989; Gick & Holyoak, 1980) and the current study, however, was the retrospective, inferential, and emergent nature of the scoring process used to classify responses as ‘analogical’. As a first step, each unique solution proposed for each analogue was coded separately. These codes, which represented individual solution strategies, were then carefully reviewed for evidence of relational similarity. If structural equivalence between the codes across the two analogues was established, this was regarded as indicative of a shared relationally-based solution strategy having been implemented for both analogues and thus as representative of ‘open analogical transfer’ having taken place. Although the solution strategies would have been successful to varying degrees if implemented in real life, they were nevertheless weighted equally as regards representation of analogical transfer as the focus of the task was to identify evidence of a shared relational strategy being utilised to resolve the two problems. The scoring strategy used to classify analogical solvers was thus specifically designed to avoid under-estimation of analogical transfer performance based on only an *a priori* recognition of certain strategies as correct, relevant, or representative of analogical problem solving (Day & Goldstone, 2012; Lave, 1988; Lobato, 2006; Nokes, 2009).

Ultimately five shared solution strategy sets representing open analogical transfer were identified – these were: displacement, using a suitable method to force the desired object to rise; extraction, using a suitable method to pull the object out; suction, using a suitable method to create a pressure vacuum to extract the object; modification, using a suitable method to enlarge access to the object; and vibration, using a suitable method to create a force to shake the desired object loose. The extraction of five possible solution sets representing analogical problem solving, in contrast to the previous use of only one set as representative of analogical transfer, reflects a major advantage of the ‘open’ method of assessment deployed in this study. Specifically, it allowed for the identification of analogical solution strategies between the two problems that would otherwise have been overlooked or missed, and that may have led to participants being classified as non-analogical solvers. Through its retrospective focus on the solutions generated, the open method was also able to reflect both deliberate and implicit forms of analogical problem solving – the occurrence of analogical transfer was recorded regardless of the extent to which this was overtly intentional on the part of the participant. This aligns with research suggesting that previously encoded knowledge can be implicitly cued through exposure to a relevant target without conscious awareness of this process and that this is a relatively common feature of real-world analogical problem solving (Chen et al., 2004; Day & Goldstone, 2012; Gentner & Smith, 2012; 2013; Holyoak, 2012; Kostic et al., 2010; Trench et al., 2016).

Despite the extended number of possible analogical solution sets, the rates of overall open transfer observed in both samples appeared to be quite low. In the pilot phase of the study, twenty-three percent ($n = 10$) of the participants were classified as analogical solvers based on the presence of one or more of the strategy sets; in the main study, thirty-three percent ($n = 194$) of the participants were classified as analogical solvers. There were also very few participants who presented more than one set of analogical solutions – two percent ($n = 1$) in the pilot study and six percent ($n = 36$) in the main study. Although low in absolute terms, it is difficult to judge if these rates should also be regarded as comparatively low due to a lack of equivalent studies. The only exception to this, albeit with critical methodological differences, appears to be the third experiment carried out by Gick and Holyoak (1980), which focussed on transfer of the convergence schema as a self-developed solution strategy. The results from this study showed that twenty-two of the forty-five participants (forty-nine percent) generated a convergence-type solution for the source problem (the general); of these, nine (forty-one percent of those who generated the solution for the source and twenty percent overall) also generated a convergence-type solution for the target (the radiation problem). Twenty-four participants (fifty-three percent) generated an ‘accumulation’-type solution for the source; of these, ten (forty-two percent of those who

generated the solution for the source and twenty-two percent overall) also generated an 'accumulation'-type solution for the target (Gick & Holyoak, 1980).

These results point to one viable explanation for the low rate of open transfer observed in the study; if participants identified a set of solution strategies for the first analogue they attempted that did not include a solution strategy suitable for analogical adaptation, this would have automatically precluded analogical transfer or at least any possible observation thereof given the way in which this was captured in the task. To assess the possible impact of this issue in the current study, the number of participants who did not generate any of the solution codes that formed part of the shared relational strategy sets was examined. Due to the unique nature of the administration of the task (for example, the availability of both analogues simultaneously; the non-specified order of completion; freedom to move between the two analogues), it was not possible to clearly designate either analogue as 'the source'. Across both analogues, however, there were very few participants – five percent ($n = 2$) in the pilot sample and seven percent ($n = 39$) in the main sample – who did not generate at least one solution strategy for either analogue that formed part of the shared relational solution strategy sets. Another factor to consider, however, was the order of task presentation in the questionnaire pack – as the thirsty-bird analogue appeared first it seemed likely that this problem would have been attempted first by a majority of the participants. To account for this, the number of participants who did not generate at least one solution strategy that formed part of the shared relational strategy sets for each analogue was checked as well. For the thirsty-bird analogue, which was presented first in the questionnaire pack, fifty-six percent ($n = 24$) of the pilot sample and forty-one percent ($n = 242$) of the main sample did not generate at least one solution strategy that formed part of the sets. In contrast, only seven percent ($n = 3$) of the pilot sample and eleven percent ($n = 65$) of the main sample did not generate at least one solution strategy that formed part of the sets for the ball-in-the-wall analogue. These percentages indicate that the issue of failing to generate a solution suitable for analogical adaptation for the first problem attempted could have been a viable contributing factor to the low overall rates of open transfer observed in the study. This, in turn, highlights a methodological weakness of the open method of assessing transfer i.e. the inability to guarantee that participants will have access to a suitable source strategy that can be used as a base for analogical transfer (Catrambone et al., 2006; Corkill & Fager, 1995; Gentner & Smith, 2013; Gick & Holyoak, 1983; Holyoak, 1984; 2012; Novick & Holyoak, 1991).

Although this limitation must be acknowledged, it is important to bear in mind that even if every participant attempted each analogue only once and in order of appearance,

forty-four percent of the pilot sample and fifty-nine percent of the main sample did generate at least one solution strategy that formed part of the shared solution sets for the thirsty-bird analogue. Of these, only approximately half (twenty-three percent for the pilot sample and thirty-three percent for the main sample overall) produced at least one set of shared relational solution strategies for the two analogues. This pattern is remarkably similar to the one obtained by Gick and Holyoak (1980) – in very rough terms, approximately half of the participants generated at least one solution that could form a base for analogical transfer; of these, only approximately half solved the second analogue they attempted through analogical adaptation of the strategy (approximately a quarter of participants overall). This, in turn, aligns fairly well with rates of spontaneous transfer observed in previous studies (Anolli et al., 2001; Antonietti, 1996; Bassok, 2003; Catrambone & Holyoak, 1989; Catrambone et al., 2006; Corkill & Fager, 1995; Cushen, 2012; Edwards et al., 2014; Gick & Holyoak, 1980; 1983; Kubricht et al., 2015; Novick & Holyoak, 1991; Pedone et al., 2001); it also lends support to the notion that analogical problem solving is a difficult task to enact successfully and may not occur that frequently, regardless of whether a pre-determined source strategy is evaluated as part of the measurement process (Anolli et al., 2001; Bearman et al., 2002; Catrambone & Holyoak, 1989; Cushen & Wiley, 2018; Francis, 1999; Kubricht et al., 2015; 2017; Markman et al., 2007; Mason & Tornatora, 2016; Monaghan et al., 2015; Novick & Holyoak, 1991; Reeves & Weisberg, 1994; Richland & McDonough, 2010). Furthermore, if one assumes that the open transfer task developed in the current study was successful in capturing a broader and more realistic form of analogical problem solving as intended, this finding could act as an important form of verification for those obtained under more strictly controlled conditions in light of concerns raised regarding the generalisability of the latter (Bearman et al., 2002; Blanchette, 2000; Chen et al., 2004; Day & Goldstone, 2012; Gentner & Smith, 2012; Holyoak, 2012; Lave, 1998; Lee, 1992; Lobato, 2006; Nokes, 2009; Novick & Holyoak, 1991; Trench & Minervino, 2015).

For those participants who did not solve analogically despite having identified a base solution strategy suitable for analogical adaptation, one viable explanation could be retrieval failure; these participants may have failed to recognise the potential relevance of the solution they formulated for the first analogue when considering approaches to resolve the problem represented in the second analogue (Anolli et al., 2001; Gentner & Colhoun, 2010; Gentner et al., 2003; Gick, 1986; Gick & Holyoak, 1980; Kostic et al., 2010; Kurtz & Loewenstein, 2007; Needham & Begg, 1991; Novick & Holyoak, 1991; Reeves & Weisberg, 1994; Thomas, 2008; Trench et al., 2016; Zook, 1991). Difficulties in the later stages of mapping and adaptation could have also played a role; and all of these processes could have been affected by the levels of shared surface similarity between the two analogues, the extent to

which the analogues were perceptually and conceptually rich (i.e. concreteness), the level of transparency between the two analogues, and the diversity of the content domains represented (Bassok, 2003; Blanchette, 2000; Catrambone et al., 2006; Day & Goldstone, 2012; Gentner & Smith, 2012; 2013; Kaminski et al., 2013; Kubricht et al., 2015; 2017; Holyoak, 2012; Ozkan & Dogan, 2012; Reeves & Weisberg, 1994; Thomas, 2008; Zook, 1991). With the exception of retrieval failure, all of these factors were also identified as potentially playing a role in the low rate of directed analogical transfer observed in the main study.

The similarity between the rate of directed transfer observed (thirty-one percent) and the rate of open transfer observed (thirty-three percent) for participants in the main sample was unexpected. The open transfer task requires participants to engage in a full and resource-intensive analogical problem solving process, including representation of the two analogues, source retrieval, mapping leading to the extraction of relevant shared structural relations between the two analogues, and adaptation of the solution strategy for the target (Anolli et al., 2001; Blanchette, 2000; Gentner & Smith, 2012; 2013; Holyoak, 2012; Keane, 1996; Krawczyk et al., 2004; Kubricht et al., 2017; Novick & Holyoak, 1991; Thomas, 2008). In contrast, the provision of a hint regarding relevance of the source in the directed transfer task obviates the need for retrieval, a step that is widely regarded as very difficult to enact effectively, and reduces demand on cognitive resources (Barnett & Ceci, 2002; Day & Goldstone, 2012; Francis, 1999; Gick & Holyoak, 1983; Holyoak, 2012; Monaghan et al., 2015; Novick & Holyoak, 1991). On this basis, it was initially anticipated that rates of open transfer would be lower than those observed for directed transfer in the sample. One explanation that could account for this not being the case is the lower-than-anticipated rate of directed transfer that was observed in the sample. Another possibility, however, pertains to the nature of the analogues that were employed in the open transfer task. In addition to being slightly simpler and less involved than the problems utilised in the directed transfer task, these analogues also shared multiple relational solution strategies. As such, it is possible that the higher-than-anticipated rate of open transfer observed was due to increased opportunities for analogical transfer to occur in combination with a method of assessment that was sufficiently flexible to account for this. This could reflect an important advantage of the open method of assessing transfer, although additional empirical work utilising analogues with varying degrees of surface and structural similarity would be needed to confirm this.

Another interesting finding yielded by the analysis was that displacement was the most common shared strategy that was suggested; this solution set was put forward by

fourteen percent ($n = 6$) of the pilot sample and twenty-one percent ($n = 135$) of the main sample and was provided more often than the other four sets of analogical solutions combined in both groups. This finding is particularly interesting as the displacement strategy for the thirsty-bird problem (inserting pebbles into the bottle to raise the level of the water) is not only widely known as a popular fable spanning several thousand years and multiple cultures, but is also based on actual avian behaviour and can thus be directly observed fairly easily (cf. Wikipedia, 2018). The displacement solution for the ball-in-the-wall problem (inserting liquid into the hole to 'float' the ball out) is also fairly well known in the form of a popular riddle. Given this, it seems very possible that participants could have had exposure to solutions for one or both analogues previously. Previous exposure to one of the analogues was not deemed to be problematic in the current study, as the variable of interest was presentation of a shared relational solution strategy between the two analogues rather than a 'correct' solution of either analogue independently. There is, however, a legitimate concern that participants could have presented solutions based on previous exposure to both problems without any recognition of the structural similarity shared between these i.e. based solely on having 'seen' both problems before (ideally this possibility should have been accounted for as part of the procedure in the current study). This concern can be seen as an instance of a larger potential criticism of the retrospective and inferential nature of the evaluation process undertaken to evaluate 'open transfer'. Specifically, it can be argued that in the absence of some form of verification regarding the use of the source in developing the solution for the target, observations of relational similarity between strategies suggested for the two analogues could simply be random or unintentional (Bassok, 2003; Catrambone et al., 2006; Gick & Holyoak, 1980; 1983; Holyoak, 2012). Although this is a clear possibility, it is important to note that a similar critique can be raised regarding the more traditional method of assessing analogical problem solving; although far less likely given the stricter level of control implemented in the two-stage process, there is no direct guarantee of deliberate analogical transfer of a given strategy in any of the available assessment techniques used to date.

Despite a number of acknowledged weaknesses, the findings generated by the open transfer method provided valuable insight into both the frequency and difficulty of analogical problem solving; and the method may prove useful as an option to triangulate findings generated using more traditional approaches to assessing analogical transfer. Additional work focusing on bridging the divide between experimental and naturalistic work in the field, particularly options incorporating the open method of assessment using variant analogues and conditions as well as studies focussing on verbalisation of the solution process, would therefore be highly recommended as a direction for future research.

7.3. Question three: The relationship between directed and open analogical transfer

Although similarity between the overall rates of directed and open transfer observed in the study was useful to consider, this did not address the critical issue of the extent to which these represented the same participants and thus provided evidence of a pattern of successful analogical performance across the two tasks. Exploration of this issue was the primary rationale for the third research question posed in the study – to establish the nature of the relationship between the rates of directed and open transfer observed in the same sample group of participants. It is worth noting that there appears to be very little previous research that has directly compared success rates for different forms of analogical transfer in the same sample of participants; and none involving the comparison of open transfer with another form of analogical problem solving.

The results of the analysis indicated that the association between the two forms of transfer was both significant and positive, although fairly weak. This was supported by an examination of the frequencies of those providing analogical solutions for the open transfer task across the three classification categories of the directed task. Only seven percent ($n = 40$) of the total sample were classified as having provided an analogical solution for the open transfer task and a non-analogical solution for the directed transfer task; whereas thirteen percent ($n = 72$) of the total sample provided an analogical solution for the open transfer task and a partial analogical solution strategy for the directed transfer task, and fourteen percent ($n = 78$) of the total sample provided an analogical solution for the open transfer task and a fully analogical solution strategy for the directed transfer task. Taken together, these results can be interpreted as indicating that participants who solved the directed transfer task analogically were more likely to solve the open transfer task analogically as well, although this trend was not as strong as would be ideal.

Despite this, this finding is important as it provides preliminary empirical evidence pointing towards the conceptualisation of analogical problem solving as a skilled activity carried out with a relatively stable level of proficiency in young adults. This supposition, in turn, underpins much of the current discussion in the extant literature, including work focussing on the development of analogical problem solving skill, changes in analogical problem solving performance across the lifespan, and ways in which to facilitate schema formation through enhancing analogical transfer (cf. Abdellatif et al., 2008; Antonietti, 1996; Barnett & Ceci, 2002; Billing, 2007; Chen & Siegler, 2013; Gentner & Smith, 2012; 2013; Gick & Holyoak, 1983; Goswami, 1991; Holyoak, 2012; Klein, 1994; Kurtz & Loewenstein,

2007; Novick & Holyoak, 1991; Reeves & Weisberg, 1994; Richland & McDonough, 2010; Zook, 1991). Although fundamental to these topics, to date there appears to be relatively little empirical work that has directly explored this proposition; thus the finding from the current study is valuable as an initial empirical validation of existing theory.

It is worth noting that a relatively high proportion of the sample provided either a non-analogical solution for both transfer tasks or a non-analogical solution for the open transfer task and a partially analogical solution for the directed transfer task (twenty-four percent ($n = 135$) and twenty-five percent ($n = 142$) respectively representing almost half of the total sample). In addition to further supporting the notion of analogical problem solving skill as relatively consistent, this result also provides additional evidence for the inherent difficulty of successful analogical transfer under variant assessment conditions (Anolli et al., 2001; Bearman et al., 2002; Catrambone & Holyoak, 1989; Cushen & Wiley, 2018; Francis, 1999; Kubricht et al., 2015; 2017; Markman et al., 2007; Mason & Tornatora, 2016; Monaghan et al., 2015; Novick & Holyoak, 1991; Reeves & Weisberg, 1994; Richland & McDonough, 2010). This was further reflected in the small number of participants who solved analogically across both tasks. Although beyond the scope of the current study, it may be particularly valuable to conduct future research focussing on this latter group as their dual categorisation suggests a more consistent and flexible use of analogy as a heuristic as well as a relatively high level of proficiency therein; identifying factors that contribute to these capabilities could be a critical step in the development of comprehensive predictive models of analogical problem solving.

Another interesting result that emerged from the analysis was the relatively high proportion of participants – eighteen percent ($n = 102$) who provided a fully analogical solution for the directed transfer task and a non-analogical solution for the open transfer task. In contrast, only seven percent ($n = 40$) of those who solved analogously for the open transfer task provided a non-analogical solution for the directed transfer task. This pattern could reflect the importance of the role played by retrieval and the extent to which obviating the need for this step in the process enhances the likelihood of analogical problem solving occurring. This aligns with a number of findings in the literature which support the value of providing a hint as a mechanism for reducing cognitive demand and enhancing rates of analogical transfer (cf. Barnett & Ceci, 2002; Bassok, 2003; Catrambone & Holyoak, 1989; Cushen, 2012; Day & Goldstone, 2012; Francis, 1999; Gick & Holyoak, 1983; Holyoak, 2012; Kubricht et al., 2017).

7.4. Question four: The relationship between analogical problem solving and analogical reasoning

Reasoning by analogy occurs in any instance where inferences are generated through the identification and comparison of shared structural relations between two situations (Chai et al., 2015; Corkill & Fager, 1995; Day & Goldstone, 2012; Gentner & Colhoun, 2010; Gentner & Smith, 2012; Harpaz-Itay et al., 2006; Holyoak, 2012; Hummel & Holyoak, 2003; Kao, 2014; Morrison, 2004; Richland & Burchinal, 2013; Simms et al., 2018; Zook, 1991). This form of reasoning underpins performance on both proportional analogy completion tasks, which are typically used as a measure of both analogical reasoning capacity and intelligence, and homomorphic and isomorphic story problem tasks, which are typically used as a measure of analogical problem solving (Abdellatif et al., 2008; Goswami, 1991; Klein, 1994; Lee, 1992; Reimann & Schult, 1996; Sternberg, 1983; Zook, 1991). Given this, it is often assumed that successful completion of both of these tasks stems from the same latent cognitive skill set and represents the same underlying capability, despite overt differences in form and scope. This assumption is so prevalent that it has led to a tendency to treat analogical reasoning and analogical problem solving as two interchangeable instances of a single broader construct; this, in turn, has fuelled the propensity to condense or amalgamate findings relevant to either phenomenon as applicable to both in much of the extant literature (cf. Abdellatif et al., 2008; Barnett & Ceci, 2002; Embretson & Schneider, 1989; Goswami, 1991; Holyoak, 1984; Kahney, 1993; Morrison, 2004; Zook, 1991). Despite this, the actual nature of the relationship between analogical problem solving and analogical reasoning is controversial; certain literature and findings support the existence of an association between the two whereas other research and theory suggests that the two are entirely unrelated (cf. Antonietti & Gioietta, 1995; Corkill & Fager, 1995; Goswami, 1991; Holyoak, 1984; Jausovec, 1993; Kahney, 1993; Klein, 1994; Kubricht et al., 2015; 2017; Ma, 2002; Novick & Holyoak, 1991; Thomas, 2008; Vendetti et al., 2014b). These conflicting theoretical understandings and contradictory empirical findings formed the basis for the fourth research question posed in the study – to identify the nature of the relationship between analogical problem solving and analogical reasoning in the sample.

It is worth noting that the current study attempted to address certain methodological flaws identified in previous studies regarding the measurement of analogical reasoning, including sample size and issues related to choice of instrumentation (cf. Antonietti & Gioietta, 1995; Corkill & Fager, 1995; Jausovec, 1993; Klein, 1994; Kubricht et al., 2015; 2017; Novick & Holyoak, 1991; Vendetti et al., 2014b). The full Raven's Advanced Progressive Matrices were used to assess non-verbal analogical reasoning; this avoided

concerns regarding ceiling effects or adaptation that may have applied in previous studies and was very successful (Antonietti & Gioletta, 1995; Kubricht et al., 2015; 2017; Mackintosh & Bennett, 2005; Raven, 2000; Raven et al., 1998). In contrast, a suitable existing test of verbal analogical reasoning was not able to be sourced; a self-developed measure designed to reflect a range of proportional analogy types and preclude certain potential sources of cultural bias was thus utilised. This measure was somewhat successful in that it did address these issues and proved to be valid for assessing a single underlying factor; however the internal consistency of the measure was low and the range of scores was somewhat limited, suggesting possible ceiling effects. Despite this, the inclusion of both verbal and non-verbal analogical reasoning in the analysis was particularly valuable; to date there appear to be no other studies in the field that have explored both forms of analogical reasoning simultaneously as regards their relationship to analogical problem solving in the same group of participants. In addition, analogical problem solving was represented by both directed and open forms of analogical transfer, which has also not been examined previously.

The results of the analyses indicated that there were significant differences in both verbal and non-verbal analogical reasoning performance on the basis of solution type for the open transfer task, although the effect sizes were small. In both instances participants who provided at least one analogical solution set had significantly higher verbal and non-verbal analogical reasoning scores than those who provided non-analogical solutions. Open analogical transfer was also significantly associated with both verbal ($\varphi = .201$) and non-verbal ($\varphi = .127$) analogical reasoning, although the strength of the relationships established was weak. The results also showed that there were significant differences in both verbal and non-verbal analogical reasoning performance on the basis of solution type for the directed transfer task, although the effect sizes were small. Participants who provided non-analogical solutions for the directed transfer task had significantly lower verbal and non-verbal analogical reasoning scores than participants who provided partially or fully analogical solutions; and participants who provided partially analogical solutions had significantly lower verbal analogical reasoning scores than participants who provided fully analogical solutions. Directed analogical transfer was also significantly associated with verbal analogical reasoning ($V = .153$), although the strength of the relationship established was weak. Directed analogical transfer was not significantly associated with non-verbal analogical reasoning ($V = .048$); possibly as a result of reduced variance or confounding due to the categorisation (Altman & Royston, 2006).

Taken together, these findings largely support the existence of a relationship between both verbal and non-verbal analogical reasoning and analogical problem solving;

although the associations were weak and the effect sizes were small, participants who presented analogical solutions for either transfer task generally exhibited higher levels of both verbal and non-verbal analogical reasoning skill. This finding aligns with previous empirical studies that have identified an association between analogical problem solving and analogical reasoning (cf. Corkill & Fager, 1995; Klein, 1994; Kubricht et al., 2015; 2017; Ma, 2002), and contradicts studies that have established no significant relationship between the two constructs (cf. Antonietti & Gioletta, 1995; Jausovec, 1993; Novick & Holyoak, 1991). This supports the argument that methodological issues may have accounted for these latter observations, including the specificity of the samples and the nature of the instruments and analogues used (cf. Antonietti & Gioletta, 1995; Corkill & Fager, 1995; Jausovec, 1993; Klein, 1994; Kubricht et al., 2015; 2017; Novick & Holyoak, 1991; Vendetti et al., 2014b). The results observed also fit with the outcomes of recent neurological and neuropsychological studies, which have identified partial similarities in areas of brain activation across proportional and story tasks (Bunge et al., 2005; Gentner & Smith, 2012; 2013; Green et al., 2012a; Hobeika et al., 2016; Holyoak, 2012; Krawczyk et al., 2010; Lee et al., 2014; Morrison et al., 2004; Vendetti et al., 2012; Vendetti et al., 2014b; Whitaker et al., 2017). This suggests that analogical performance on both tasks may draw on a common set of component skills and corresponds with theoretical interpretations of similarity between the two tasks based on shared solution component processes such as mapping and adaptation as well as identical underlying configurations (Barnett & Ceci, 2002; Corkill & Fager, 1995; Gentner & Markman, 1997; Gentner & Smith, 2012; 2013; Holyoak, 1984; Kahney, 1993; Kubricht et al., 2017; Lee, 1992; Zook, 1991).

Although the results of the study suggest that analogical problem solving and analogical reasoning are related, it is essential to take account of the strength of these observed associations and differences; these were very weak in nature. This supports previous work suggesting that there are also critical distinctions between the two tasks and the underlying constructs that they assess (Goswami, 1991; Holyoak, 1984; 2012; Kahney, 1993). In contrast to story problems, proportional analogies can only be resolved through the use of analogy; the purpose of the task is thus more focussed and immediately apparent (Antonietti & Gioletta, 1995; Antonietti et al., 2000; Goswami, 1991; Holyoak, 1984; Kubricht et al., 2017; Novick & Holyoak, 1991). Proportional analogies also incorporate the base as an intrinsic component of the task; as such, there is no need to recognise and retrieve a suitable source which substantially reduces the amount and complexity of the cognitive processing required (Antonietti & Gioletta, 1995; Antonietti et al., 2000; Goswami, 1991; Holyoak, 1984; Kahney, 1993; Kubricht et al., 2015; 2017; Lee, 1992; Novick & Holyoak, 1991). Relative to story problems, proportional analogies tend to involve simpler relations

based more on shared features or attributes and contain only essential information; this reduces the level of cognitive demand required for mapping and adaptation (Goswami, 1991; Holyoak, 1984; 2012; Kahney, 1993; Novick & Holyoak, 1991). As such, proportional analogies can also be seen as more restricted in scope, less complex, and less realistic than typical story problems (Holyoak, 2012; Kahney, 1993; Lee, 1992). On the basis of these differences, it has been argued that the two tasks capture largely distinct sets of skills and capacities and thus represent separate forms of reasoning by analogy that should be treated as two individual constructs (Goswami, 1991; Holyoak, 1984; Novick & Holyoak, 1991). The weak nature of the links between analogical problem solving and both verbal and non-verbal analogical reasoning observed in the current study lend support to this proposition and suggest that although there are certain commonalities, the tendency to treat analogical problem solving and analogical reasoning as slightly variant manifestations of the same underlying ability is not substantiated empirically (cf. Abdellatif et al., 2008; Barnett & Ceci, 2002; Embretson & Schneider, 1989; Goswami, 1991; Holyoak, 1984; Kahney, 1993; Morrison, 2004; Zook, 1991). The findings also suggest the propensity for conflating evidence related to either phenomenon in much of the extant literature is not warranted unless verified through re-conceptualisation and extended investigation.

Although all of the relationships identified between analogical problem solving and both forms of analogical reasoning were weak, it was clear from the results that the associations between verbal analogical reasoning and both forms of analogical transfer were stronger than those identified between non-verbal analogical reasoning and analogical problem solving, particularly for directed transfer. Although speculative, one possible explanation is that this could reflect differences in the demands created by verbal (semantic) and figural proportional analogies during the solution process. Although both types of analogies are regarded as essential measures of induction and analogical reasoning, they also vary in terms of complexity, abstractness, novelty, and content (Green et al., 2012a; Lohman, Korb, & Lakin, 2008; Melis & van Boxtel, 2001; Richland & Burchinal, 2013; Schiano et al., 1989; Tinsley & Dawis, 1974; Whitely, 1976). Figural analogies incorporate shapes, objects, or geometric patterns - typically the relations between these are based on a relatively circumscribed set of rules reflecting changes in elemental features such as position, size, number, and colour (Blanchette, 2000; Chai et al., 2015; Hobeika et al., 2016; Kahney, 1993; Mulholland et al., 1980; Whitely, 1976). The use of visual elements tends to reduce the extent to which context-based and culturally-specific knowledge is required in order to successfully reason analogically (Schiano et al., 1989; Tinsley & Dawis, 1974). Figural analogies may also “...rely minimally on language skills, if it is assumed that such problems can be solved without describing or verbally labelling the relations between the

items" (Edwards, Figueras, Mellanby, & Langdon, 2011, pp. 190-191). In contrast, verbal analogies rely on an infinitely larger set of conventionalised semantic relations and categories; they tend to require greater levels of abstraction and a more nuanced understanding of the context and connotation of the terms involved (Green et al., 2006; Kahney, 1993; Richland & Burchinal, 2013; Tinsley & Dawis, 1974; Vendetti et al., 2012; Vendetti et al., 2014b). They also rely heavily on verbal ability and linguistic competence, and tend to be more complex based on the number of factors that have to be considered during the analogical reasoning process (Green et al., 2006; Schiano et al., 1989; Tinsley & Dawis, 1974; Vendetti et al., 2012). Given these distinctions, it seems plausible to suggest that the complex processes required to successfully retrieve, map, and adapt high-level structural relations between story-based analogues (i.e. analogical problem solving) may align more closely with the complexity required to identify, interpret, and map analogical relations between verbal elements relative to the more circumscribed process required to resolve figural proportional analogies. This could account for the relatively stronger relationship observed between verbal analogical reasoning and both forms of analogical transfer in the current study, although further research would be needed in order to verify this.

As a whole, the results of the analyses suggested that analogical problem solving and analogical reasoning are related, but only to a limited extent. This finding contributes substantially to existing evidence and theory regarding the association between these two forms of reasoning by analogy, both in terms of enhanced methodological rigour, and as a preliminary step towards reconciling theoretical tensions and empirical conflicts currently evident in the extant literature. The relatively stronger relationship observed between analogical problem solving and verbal analogical reasoning in contrast to non-verbal analogical reasoning represents another important and novel contribution to the field; future research exploring potential explanations for this discrepancy and associated factors could be particularly valuable as a means to further clarify understandings of the processes underpinning successful analogical resolution in both task types.

7.5. Question five: The relationship between analogical problem solving and self-reported heuristic strategy preference

Although analogy has been identified as one of the most common and effective approaches to problem solving, it is important to bear in mind that it only represents one of a number of possible heuristic strategies that can be deployed (Antonietti et al., 2000; Billing, 2007; Chen & Siegler, 2013; Gick, 1986; Güss & Wiley, 2007; Koichu et al., 2003; Lee,

1992; Miller, 2014; Wang & Chiew, 2010). These strategies differ in terms of their efficacy, ease of application, and the frequency with which they are utilised relative to the demands of the problem and problem solving context as well as individual characteristics of the problem solver (Antonietti et al., 2000; Billing, 2007; Cho, 2010; Condell et al., 2010; Day & Goldstone, 2012; Fum & Del Missier, 2001; Gick, 1986; Jonassen, 2000; Kahney, 1993; Mayer, 1998; Ohlsson, 2012; Pretz et al., 2003; Taggart & Valenzi, 1990; Treffinger & Selby, 2004; Treffinger et al., 2008). As such, preference as well as skill may play an important role in determining the choice of heuristic strategy deployed in a given situation; this forms the basis for habitual problem solving style, relatively consistent approaches people tend to adopt when attempting to solve new problems (Antonietti & Gioletta, 1995; Bailey, Littlefield, & Geary, 2012; Hamlen, 2018; Martin, 1998; Treffinger et al., 2008). Despite its clear relevance, to date there appears to be no research that has directly explored the link between analogical problem solving and habitual problem solving style, although a number of studies have explored related factors such as cognitive learning style and metacognition (cf. Antonietti & Gioletta, 1995; Gary et al., 2012; Haynie et al., 2004; Hsu & Wedman, 1994; Jausovec, 1993; Klein, 1994; Muldner & Conati, 2010). This represents a crucial gap in the extant literature, particularly as an enhanced understanding of the role played by choice of heuristic strategy could contribute to the development of more advanced theoretical models and approaches to facilitate schema development.

It is important to note that despite extensive searching, a suitable pre-existing instrument for assessing habitual problem solving style as represented by heuristic strategy preference was not able to be sourced. As a result, the *Problem Solving Strategy Questionnaire* developed by Antonietti et al. (2000) was adapted for the current study. The original measure contained five paragraph descriptions, each of which represented a separate cluster of problem solving heuristics (visualisation, free production, combining, step-by-step, and analogy); these were grouped together based on theoretical similarity (Antonietti et al., 2000; Güss & Wiley, 2007; Metallidou & Platsidou, 2008). In the adapted measure, each description was split into three individual items and one additional item was developed in each instance, thus each of the original strategy clusters was theoretically represented by four separate items. During preliminary analysis, however, this structure was not supported empirically; the results of the factor analysis instead suggested a single overarching factor as well as four smaller factors. Items that loaded on the first factor included a combination of strategies from the step-by-step and visualisation clusters – essentially this factor represented both highly methodical, sequenced approaches and processes linked to insight, restructuring the problem, and shifting perceptions of key problem features (Antonietti et al., 2000; Güss & Wiley, 2007; Metallidou & Platsidou, 2008).

Items that loaded on the second factor included a combination of strategies from the combining and free production clusters – essentially this factor represented both processes to generate as many solutions as possible as freely as possible and strategies based around novel or unusual synthesis (Antonietti et al., 2000; Güss & Wiley, 2007; Metallidou & Platsidou, 2008; Miller, 2014). The internal consistency reliabilities for both of these subscales were low but acceptable (Murphy & Davidshofer, 2005). Items that loaded on the third factor included only strategies from the analogy cluster – this factor represented approaches to problem solving based on the identification and extraction of corresponding relations and adaptation (Antonietti et al., 2000; Gentner & Smith, 2012; Gick & Holyoak, 1980; Güss & Wiley, 2007; Holyoak, 2012; Metallidou & Platsidou, 2008; Miller, 2014; Yanowitz, 2001). The internal consistency reliability for this subscale was moderate-to-high. The final factor contained a mixture of approaches that were ultimately labelled as ‘practical’ – the internal consistency for this subscale was so low, however, that it was not considered further during the analysis.

The findings from these analyses were particularly useful as they not only provided a preliminary psychometric validation of a set of items designed to measure a neglected construct but also provided a new theoretical formulation for understanding the links between different types of problem solving heuristics. As such, and although a necessary precursor for the fifth research question, the development and psychometric analysis of the *self-reported heuristic strategy preference measure* in the current study can also be seen as an important contribution to existing work in the field in its own right. Despite this, the properties of the adapted scale were not ideal, and further work to develop and refine suitable instrumentation to measure habitual problem solving style and heuristic strategy preference is strongly recommended.

Of the various heuristic strategy groupings identified, the conscious choice to deploy analogy as a problem solving mechanism seemed the most likely to relate to analogical problem solving. This was based on an assumption that a preference for recalling and using principles from relevant past problems when attempting to solve a new problem might encourage active searching for suitable sources in long-term memory and hence initiate or promote the full analogical problem solving process (Antonietti et al., 2000; Gentner & Smith, 2012; Gick & Holyoak, 1980; Güss & Wiley, 2007; Holyoak, 2012; Yanowitz, 2001). The results of the analysis indicated that this was not the case; self-reported heuristic strategy preference for analogy was not significantly related to either directed or open analogical transfer in the current study. This finding may reflect differences in preference and aptitude; although an individual may be drawn towards thinking of previous instances this does not

guarantee that they will be able to effectively recognise, map, and adapt corresponding shared relational structures even if these exist (Anolli et al., 2001; Bailey et al., 2012; Holyoak, 1984; Pashler et al., 2008; Thomas, 2008). Furthermore, this may highlight the critical importance of both representation and recognition as a core component of retrieval; even if a search for suitable analogues in long-term memory is initiated, this will be unsuccessful unless the conceptual structure of the source and target overlap sufficiently and this similarity can be accessed using suitable semantic cues (Bassok, 2003; Chai et al., 2015; Cushen, 2012; Cushen & Wiley, 2018; Gentner, 1989; Gentner & Colhoun, 2010; Gentner & Smith, 2013; Gick & Holyoak, 1980; 1983; Holyoak, 1984; Kahney, 1993; Thomas, 2008; Zook, 1991). This has important implications, particularly for instructional practice, as it suggests that a simple directive to consider previous exemplars without sufficient specification is unlikely to function as an effective mechanism for facilitating analogical transfer. This supposition aligns with previous research regarding the relative efficacy of various techniques to encourage schema development, for example, general and directive hints, forced comparison, and exposure to concrete examples (cf. Antonietti, 1996; Catrambone et al., 2006; Catrambone & Holyoak, 1989; Chen & Mo, 2004; Clement, 1994; Edwards et al., 2014; Gentner et al., 2003; Gick & Holyoak, 1983; Gick & Paterson, 1992; Minervino et al., 2017; Novick & Holyoak, 1991; Richland & McDonough, 2010; Speicher & Kehrhahn, 2009).

The results also indicated that self-reported heuristic strategy preference for free production/combining techniques did not differ significantly on the basis of either directed or open analogical problem solving. This was slightly surprising as these heuristic strategies are particularly associated with creativity, which has been relatively consistently linked with analogical problem solving in the literature (Corkill & Fager, 1995; Cushen, 2012; Cushen & Wiley, 2018; Klavir & Gorodetsky, 2011). This may, however, again reflect a distinction between preference and aptitude (Bailey et al., 2012; Pashler et al., 2008). Self-reported heuristic strategy preference for step-by-step/visualisation strategies did not differ significantly on the basis of open transfer; however significant differences were identified on the basis of directed transfer. Specifically, participants who provided non-analogical solutions for the aquarium analogue reported higher levels of preference for approaching novel problems using step-by-step and visualisation heuristic strategies than participants who provided partial or full analogical solutions. The sequential and insight-based solution approaches represented by the step-by-step and visualisation clusters respectively are often seen as directly contrasting; the first represents a separation or breakdown of the problem into smaller sub-problems whereas the second represents a sudden realisation regarding the whole (Antonietti et al., 2000; Batchelder & Alexander, 2012; Güss & Wiley, 2007;

Kahney, 1993; Koichu et al., 2003; Metallidou & Platsidou, 2008; Miller, 2014; Öllinger et al., 2008; Wang & Chiew, 2010). Although highly speculative, it is possible that if either of these relatively extreme approaches were adopted as the preferred method of resolving the directed transfer task, they could have masked the importance of the source and the hint provided regarding its relevance in the directed transfer task; specifically participants may have become so focussed on resolving the target problem through either a re-representation or a decomposition that they ignored or missed corresponding structural relations with the source or simply failed to consider the source altogether. In contrast, for the open transfer task participants were required to solve both problems; thus adopting either of these heuristic approaches for one of the analogues may not have been problematic as this process could have still primed participants to resolve the second analogue analogically. This interpretation tentatively suggests that a preference for both step-by-step and insight approaches may be counter-productive to analogical problem solving; however further exploration and empirical evidence is required before any formalised conclusions regarding this association can be drawn.

In order to more fully explore potential links between self-reported heuristic strategy preference and analogical problem solving, including the strategies that were discarded as part of the 'practical' factor, additional analyses were carried out that examined whether each individual item in the adapted scale differed on the basis of directed and open transfer. Most of the individual items, which represented distinct problem solving heuristic methods or behaviours, were not significantly linked to either directed or open transfer. There was, however, one item that differed significantly on the basis of both forms of analogical problem solving - participants who presented partial or full analogical solutions for the directed transfer task or analogical solutions for the open transfer task indicated a higher preference for ruling out aspects of a problem that did not seem strictly relevant.

Although preference does not necessarily equate to ability, this finding suggests that approaching a novel problem with the intention of separating critical and non-essential information may encourage the solver to discard irrelevant details and focus on the identification of shared structural correspondences with other previously encountered problems (Antonietti & Gioletta, 1995; Bassok, 2003; Cushen, 2012; Gentner, 1989; Gentner & Smith, 2013; Gick & Holyoak, 1980; 1983; Holyoak, 2012; Jonassen, 2000; Kaminski et al., 2013; Lee, 1992; Pretz et al., 2003; Thomas, 2008; Zook, 1991). This approach may thus facilitate identification of a shared relational structure and schema extraction through directing attention towards structural correspondences rather than surface features; this supposition aligns with findings regarding the success of other facilitation methods such as

comparison, manifest description, and summary presentation (Barnett & Ceci, 2002; Bassok, 2003; Billing, 2007; Catrambone & Holyoak, 1989; Clement, 1994; Day & Goldstone, 2012; Edwards et al., 2014; Gentner et al., 2003; Gick & Holyoak, 1983; Klein, 1994; Kubricht et al., 2015; 2017; Kurtz & Loewenstein, 2007; Markman et al., 2007; Minervino et al., 2017; Pedone et al., 2001). Another interesting possibility suggested by this result is a potential link to field in/dependence, which refers to an individual's ability to differentiate between important and non-important elements in complex patterns and extract the former for later use (Antonietti & Gioletta, 1995; Hsu & Wedman, 1994; Witkin et al., 1975; Yamazaki, 2005). The association between field in/dependence and analogical problem solving has not been studied extensively, however it is one of the few cognitive style factors that has been consistently related to successful analogical problem solving (Antonietti & Gioletta, 1995; Hsu & Wedman, 1994). Field in/dependence is a skill, thus it is not directly linked to a preference for discarding irrelevant information, however it has been suggested that a higher level of proficiency in a certain skill may lead to a preference for utilising that skill and that a preference for a particular approach may enhance successful implementation of that approach leading to skills development (Bailey et al., 2012; Pashler et al., 2008). As such, a preference for discarding irrelevant information may be associated with a higher field independence capacity; this issue represents an interesting direction for future research. Further exploration of the efficacy of discarding irrelevant information as a heuristic strategy during analogical problem solving would also be highly recommended; particularly as a series of positive findings in this regard could have very useful implications for instructional practice (Billing, 2007; Lightner et al., 2008; Richland & Simms, 2015; Vendetti, Matlen, Richland, & Bunge, 2015).

Only one other item differed on the basis of directed transfer – this item represented a preference for systematically planning and ordering steps and formed part of the step-by-step/visualisation subscale. Participants who indicated a higher preference for this approach produced significantly more non-analogical solutions, although no difference in levels of preference for this strategy were identified between partial and full directed analogical solvers. As was the case for the total step-by-step/visualisation cluster, one possible explanation for this could be that participants may have missed structural correspondences underpinning the aquarium problem as a whole or failed to consider the source at all as a result of becoming narrowly focussed on breaking the problem down into smaller elements and organising these. For the open transfer task, a preference for creating many possible solutions and choosing the best one, a strategy that formed part of the free production/combining subscale, was identified as significantly higher for non-analogical problem solvers. This result may simply reflect the nature of the analogues used in the task,

however, as both problems (the thirsty-bird and the ball-in-the-wall) could be resolved in many ways and participants who attempted to generate multiple solutions may have thus identified effective non-analogical solution strategies they felt were best suited to resolve the situations independently. This supposition supports previous research suggesting that participants may choose to resolve potential analogues using other solution strategies if these are deemed to be easier to implement or more likely to be successful (Antonietti, 1996; Gick & Holyoak, 1983; Holyoak, 1984; Reed et al., 1974). Additional research to establish if this finding can be replicated using more restrictive analogues would thus be recommended.

Only one other individual strategy was identified as differing significantly on the basis of open transfer – a preference for representing the problem in a different way, for example, by using pictures, graphs, or mind-maps. Participants who produced analogical solution sets for both analogues reported having a higher preference for this strategy – a finding that was particularly interesting in light of a number of questionnaire responses collected from the sample that included drawings or images for one or both of these analogues. A possible, albeit speculative explanation, could be that both analogues that were utilised in the open transfer task contained verbal descriptive information that was relatively easy to visualise or represent graphically; including elements that facilitated recognition of relational similarity between objects and actions and one-to-one mapping of correspondences (Barnett & Ceci, 2002; Chai et al., 2015; Kaminski et al., 2013; Riding & Douglas, 1993). This supposition would align with previous findings regarding the link between analogical problem solving and presentation modality, particularly the use of detailed visually-based cues and animations as facilitators of analogical transfer (Beveridge & Parkins, 1987; Chen, 1995; Chen et al., 2010; Kubricht et al., 2015; 2017; Pedone et al., 2001).

It is very interesting to note that a modal preference for visual information was also linked to the provision of an analogical solution for the open transfer task. Modal preference, which represents a preferred way of receiving information, was originally incorporated into the study purely as a motivational mechanism but was later analysed in order to assess whether the written format of the tasks played any role in determining analogical performance (Canfield, 1980, as cited in Pettigrew & Buell, 1989; Matthews, 1991; Pettigrew & Buell, 1989). There were no significant differences in modal preference on the basis of the directed transfer task. The results for the open transfer task, however, indicated that participants who provided at least one analogical solution set for the two analogues also expressed a higher preference for receiving information in an iconic (visual) format. This supports the suggestion that these two analogues may have been particularly amenable to a

verbal-visual conversion that incorporated sufficient information to permit extraction of a shared relational structure, although this explanation is speculative in nature (Barnett & Ceci, 2002; Chai et al., 2015; Kaminski et al., 2013; Riding & Douglas, 1993). The only other significant finding regarding modal preference was that participants who preferred receiving information aurally, i.e. through listening, were less likely to provide an analogical solution for the open transfer task. The reasons for this difference are unclear as there does not appear to be a logical theoretical link between identifying a shared relational strategy for the two analogues and a preference for receiving information via sound. This difference may therefore simply be spurious or could perhaps reflect a process-related issue; possibly participants who were more inclined towards a listening method of receiving information that did not match to the written presentation format of the tasks invested less effort or developed fewer solution strategies overall. These explanations are, however, highly speculative and should be treated with extreme caution.

When considered as a whole, the analyses exploring the potential links between heuristic strategy preference as representative of habitual problem solving style and analogical problem solving yielded a number of important and novel findings that could contribute significantly to enhancing both theory and practice in the field. Although further research is needed in order to replicate and substantiate these findings and further develop possible explanations and interpretations for these, the potential implications of these findings for instructional practice are particularly interesting to consider and represent important avenues for further empirical work regarding the facilitation of analogical transfer and schema extraction.

7.6. Question six: The relationship between analogical problem solving and various demographic factors

Despite its clear relevance and significance, to date there appear to be no studies that have directly explored the phenomenon of analogical problem solving in the South African context. This omission is critical to address, as previous research suggests that a number of important problem solving factors may vary on the basis of cultural experience, knowledge, conventions, and practice, including interpretation, strategy choice, and the formation of stored information (Buchtel & Norenzayan, 2008; Chen et al., 2004; Güss & Wiley, 2007; Pretz et al., 2003; Richland et al., 2010). The South African population is also unique in terms of linguistic, ethnic, and socioeconomic diversity (Beck, 2014; Encyclopaedia Britannica Online, 2018; South Africa.info, 2015; Spaull, 2013a; van der Berg et al., 2011). As such, exploring potential links between analogical problem solving and various

demographic factors in a South African context could be highly valuable both as regards the development of local theory and as a means of contributing towards expanding understandings internationally. This motivation underpinned the sixth research question posed in the study which was to explore the nature of the associations between gender, home language, type of schooling, and socioeconomic status and both directed and open analogical transfer in the sample.

The results of the analyses indicated that gender was not significantly associated with performance on the open transfer task; this generally aligns with work by Antonietti and Gioletta (1995), who found no differences in analogical problem solving performance on the basis of gender across four of their five studies. There was, however, a significant, albeit weak, association between gender and performance on the directed transfer task – fewer males produced analogical solutions relative to females. This distinction remained even after factoring in the substantial gender imbalance in the sample – seventy six percent of the participants in the main study were female. Relative to the total number of males and females in the sample, the full analogical solution rate for females was approximately thirty-four percent whereas the rate for males was only approximately twenty-three percent; similarly the non-analogical solution rate for males was approximately forty-one percent whereas the rate for females was only approximately twenty-eight percent. This finding directly contradicts the results obtained by Antonietti and Gioletta (1995) in their first study; their analysis indicated that their male participants provided significantly more analogical solutions than their female participants after being provided with a non-specific hint regarding the relevance of the source.

Antonietti and Gioletta (1995) proposed that the ‘masculinised’ nature of the content of their analogues (one was based in the engineering field and the other in the medical field) could have played a role in facilitating male analogical transfer performance in their studies; it is thus possible that the more neutral nature of the analogues used in the current study for both tasks reduced the likelihood of stereotypical gender-based assumptions regarding content coming into play, although this does not account for the observed female advantage for directed transfer (Meyers-Levy & Loken, 2015; van Broekhuizen & Spaul, 2017). Although highly speculative, one explanation for this advantage could be that males in the study were less likely to adopt or work with the hint provided regarding the relevance of the source passage as a result of a gender-based differences in task approach. These include a reduced tendency to follow instructions, a higher inclination towards intellectual risk-taking and risky guessing, a greater likelihood of experiencing and expressing confidence in one’s own work, and a higher tendency towards independence and agentic action (Byrnes, Miller,

& Schafer, 1999; Koenig, 2018; Meyers-Levy & Loken, 2015; Pallier, 2003; Pichay, Aldave, Baligat, Linezo, & Tanedo, 2015; Severiens & ten Dam, 1994). It has also been proposed that on average females tend to process information more comprehensively, more thoughtfully, and with less reliance on immediate cues; whereas males tend to process information more selectively and intuitively; this could also potentially account for a female advantage in utilising both the hint and the source itself in the directed transfer task (Darley & Smith, 1995; Meyers-Levy & Loken, 2015). It is worth noting, however, that these explanations are process-based rather than reflective of a distinction in underlying analogical problem solving skill on the basis of gender; this interpretation is supported by the lack of significant differences observed for the open transfer task. Additional research to verify whether any stable gender-based differences for different forms of analogical problem solving can be identified would thus be highly useful.

Due to the relatively high number of English first-language speakers in the sample (approximately fifty-seven percent), the large number of other home languages identified by participants, and the use of English as the language of presentation for the measures, home language was categorised as 'English home-language' or 'other home-language' for the analyses in the current study. Although necessary for practical purposes, this did limit the utility of the results and the generalisability of the conclusions for this variable; as such, further comparative work incorporating a fuller range of languages drawn from different families would be highly recommended. The results of the analyses indicated that both directed analogical transfer and open analogical transfer were significantly related to home language in the study, although these associations were weak. In both instances, participants who spoke English as a home language were more likely to provide analogical solutions for either task. This finding contradicts previous work by Cushen (2012), who found no differences in analogical problem solving performance on the basis of home language. It does, however, align with several other studies suggesting that transfer rates are lower for bilingual or multilingual participants who receive the target problem in a language they are less proficient or fluent in (Francis, 1999; Fukumine & Kennison, 2016; Wakebe et al., 2015). Francis (1999) suggests that this may be due to an increase in processing demands or a link between language and cultural context. Yanowitz (2001) suggests that there are also integral links between comprehension and reading skills and successful analogical transfer; less fluent readers or those with less proficiency may struggle to produce a coherent representation of the information presented or may find it difficult to distinguish between relevant and arbitrary information. This would further support a potential advantage for solvers with greater levels of oral and written proficiency in the language of presentation. Despite this, it is necessary to be very cautious when interpreting findings regarding home

language in the current study as a result of potential confounding with both socioeconomic status and type of schooling. This was anticipated given the continued impact of segregation and differential access to economic resources on the basis of race that resulted from both colonialist and Apartheid practices in South Africa (Beck, 2014; Marais, 2010; Spaull, 2013a; van der Berg et al., 2011); it was also confirmed empirically as all three variables were significantly related to one another in the current study.

Socioeconomic status (SES) can be defined as “... *access to economic and social resources and the social positioning, privileges, and prestige that derive from these resources*” (Duncan & Magnuson, 2012, p. 378); it is considered a difficult construct to measure effectively despite its recognised growing importance in many spheres of human life (Duncan & Magnuson, 2012; Farah, 2017; Spaull, 2013a; Ursache & Noble, 2016). In the current study, socioeconomic status (SES) was estimated using parental occupation, parental education, and standard of living estimators (based on possession of certain resources in the home environment); these factors were used to classify participants into one of three SES categories (low, average, or high) based on the range of scores obtained in the sample. Despite their relative lack of sophistication, these categories were deemed to be reasonably representative of the broader spectrum of SES in the South African population based on the wide range of responses received which were indicative of highly variant SES conditions in the sample. Nevertheless, the limitations of this process must be kept in mind – particularly the relatively arbitrary nature of the cut-off points used to distinguish between the categories which could artificially reduce inter-group variance (Altman & Royston, 2006).

The results of the analyses indicated that socioeconomic status (SES) was significantly related to both directed and open analogical transfer in the sample; participants with a higher SES were more likely to produce analogical solutions for either task. This finding is particularly important as to date there appear to be no previous studies that have directly examined differences in analogical problem solving performance on the basis of SES. There is, however, a growing body of evidence linking SES and a range of other cognitive abilities, including executive functioning and intelligence; both of these have also been shown to relate to analogical reasoning capacity (Duncan & Magnuson, 2012; Farah, 2017; Hackman, Farah, & Meaney, 2010; Hackman, Gallop, Evans, & Farah, 2015; Richland & Burchinal, 2013; Simms et al., 2018; von Stumm & Plomin, 2015). SES has also been found to either determine or relate to a wide range of factors that underpin neurocognitive development - including the capacity to problem solve - such as physical health, nutrition, home environment quality, access to schooling, learning environment quality, degree and

type of parent-child interaction, level of stimulation, and the promotion of cognitive skills (Duncan & Magnuson, 2012; Farah, 2017; Hackman et al., 2010; Hackman et al., 2015; Ursache & Noble, 2016). Given this, an association between SES and analogical problem solving capacity seems theoretically sensible; the results from the current study thus provide an important empirical base from which to extend existing understandings of the role played by SES in analogical transfer and cognition more generally.

One factor that is often determined by socioeconomic status is education level and quality; this is particularly evident in the South African context where the schooling system remains highly stratified along geographic and economic lines as a result of historical policies and practices (Spaull, 2013a; Spaull, 2013b; van der Berg et al., 2011; Yamauchi, 2011). Government schools, which are funded using public money or a combination of funding obtained from the government and fees, can be divided into two types based on their history and economic profile (Spaull, 2013a; Spaull, 2013b). Approximately a quarter, largely those developed to cater for urbanised, wealthier, White students during the Apartheid era, are fairly well-resourced, attract high quality educators, and offer students access to a range of facilities and learning opportunities (Spaull, 2013a; van der Berg et al., 2011). In contrast, most other government schools continue to struggle with the legacy left by the Apartheid system and remain highly under-resourced; issues such as a lack of access to basic facilities and learning resources (e.g. running water, classrooms, textbooks), high rates of teacher absenteeism, high rates of grade repetition and learner dropout, and ongoing management difficulties are common (Spaull, 2013a; van der Berg et al., 2011). There are also a range of independent (private) schools which derive their income primarily from fees and donations rather than public funding (van der Berg, Van Wyk, Burger, Kotzé, Piek, & Rich, 2017). These schools, which tend to cater to students from wealthier backgrounds whose parents can afford to pay the necessary fees, offer “market-value” education; as such, they tend to be extremely well-resourced, offer a large number of extramural activities and opportunities for development, and employ highly qualified and experienced teachers (Immelman & Roberts-Lombard, 2015; van der Berg et al., 2017). Government and independent schools also often have distinct assessment and learning cultures; they typically follow different curricula and write examinations that are overseen by different examination boards. In the current study, type of schooling was categorised as ‘government’ or ‘private’ – unfortunately it was not possible to account for the distinction in types of government schools which was problematic as this could have masked possible differences between the two groups.

The results of the analyses indicated that there was no significant difference in directed analogical transfer performance on the basis of type of schooling (government or

private). There was, however, a significant, weak association between type of schooling and open analogical transfer; participants from private school backgrounds were more likely to provide analogical solution strategies than participants from government school backgrounds. This relationship could stem from variations in levels of exposure to and experience with analogical problem solving as a result of education type, including distinctions in syllabus, teaching approach, and learning milieu such as requirements for higher order thinking; use of inference-based strategies and multiple exemplars; implementation of comparison and scaffolding; relational language use; and modality switching as components of classroom practice (Billing, 2007; Brown & Clement, 1989; Day & Goldstone, 2012; Kubricht et al., 2015; 2017; Richland & Simms, 2015; Richland, Stigler, & Holyoak, 2012; Vendetti et al., 2015). This explanation does not account, however, for the lack of observed difference between the school types for directed analogical transfer. Although highly speculative, this particular finding could provide insight into the nature of the potential advantage afforded by private schooling for analogical problem solving in the sample. Specifically, this type of schooling could engender a greater level of skill in representation, recognition, and retrieval of relevant analogues; this distinction would fall away in the directed transfer task as a result of the hint which largely negates the needs for these steps and instead directs attention towards the later analogical processes of mapping and adaptation (Barnett & Ceci, 2002; Day & Goldstone, 2012; Francis, 1999; Gentner & Smith, 2013; Gick & Holyoak, 1983; Holyoak, 2012; Monaghan et al., 2015; Novick & Holyoak, 1991). To date there appears to be no previous work that has directly explored the link between type of schooling and analogical problem solving; the current findings thus represent critical baseline empirical evidence for the potential significance of this factor in analogical theory. Further research exploring the nature of the associations between different schooling systems, types of instructional practice, and rates of analogical transfer would thus be highly recommended.

As a whole, a number of significant relationships were identified between the various demographic factors and analogical problem solving in the sample. These findings contribute towards a better understanding of analogical transfer cross-culturally and in complex environments and emphasise the importance of exploring the universality of existing theory and evidence. Despite this, the differences identified were also highly preliminary; additional work is necessary prior to drawing any definitive conclusions.

7.7. Question seven: Predicting analogical problem solving

The seventh research question posed in the study explored the extent to which verbal and non-verbal analogical reasoning, the different heuristic strategy preference clusters (step-by-step/visualisation, free production/combining, and analogy), and certain of the demographic variables (gender, home language, type of schooling, and socioeconomic status) predicted analogical problem solving in the sample. A series of multinomial (for directed analogical transfer) and binomial (for open analogical transfer) logistic regressions were calculated to model the effects of these predictors; logistic regression was used due to the categorical nature of the criterion variables (Hosmer & Lemeshow, 2000; Howell, 2013; Huck, 2008). Analysis of the relationships between the various predictors indicated that home language, type of schooling, and socioeconomic status were too closely associated to one another to be entered into the same regression model without creating multicollinearity concerns (Hosmer & Lemeshow, 2000; Huck, 2008; Mason & Perreault, 1991). As a result, six separate models were created; in each case all six of the other predictor variables and one of home language, type of schooling, or socioeconomic status were included.

All three of the predictive models for directed analogical problem solving were significant; all could also be classified as useful based on a cut-off of a twenty-five percent or more improvement over chance. The analyses also indicated that step-by-step/visualisation heuristic strategy preference, gender, and home language were significant predictors of directed analogical transfer; whereas non-verbal analogical reasoning, analogy heuristic strategy preference, free production/combining heuristic strategy preference, type of schooling, and socioeconomic status did not significantly predict directed transfer in any of the models. Verbal analogical reasoning functioned as a significant predictor of directed analogical transfer in two of the three models; it was not, however, significant when included in the same model as home language. All three of the predictive models for open analogical problem solving were also significant; although they represented a substantial improvement over chance the estimates fell just below the ideal cut-off of twenty-five percent. The results indicated that verbal analogical reasoning, home language, type of schooling, and socioeconomic status significantly predicted open analogical transfer performance in the sample whereas none of the other predictors – non-verbal analogical reasoning, the three heuristic strategy preference clusters, and gender – were significant.

Of the various predictor variables, only home language and verbal analogical reasoning predicted both directed and open analogical problem solving fairly consistently. For directed transfer, only home language was significant when both variables were entered

into the same model however both predictors were significant when entered together for open transfer and verbal analogical problem-solving was also a significant predictor in the other four models that did not include home language. The direction of performance was also consistent across the different models – first-language English speakers and those with higher verbal analogical reasoning scores were more likely to produce analogical solutions for both tasks. The significance of home language as a predictor was anticipated based on the associations observed in the earlier analyses; in addition, this fits with previous research indicating that proficiency in the language used to present the target analogue plays a role in determining transfer difficulty (Francis, 1999; Fukumine & Kennison, 2016; Wakebe et al., 2015). Verbal analogical reasoning was also shown to relate significantly to analogical problem solving in the sample, thus its significance as a predictor provides additional confirmation of the theoretical and empirical links proposed between the two constructs in the broader literature and in the current study. This includes propositions that both tasks draw on similar component skills and express the same broad relational configuration, as well as research outcomes indicating a significant association between the two variables (Barnett & Ceci, 2002; Corkill & Fager, 1995; Gentner & Markman, 1997; Gentner & Smith, 2012; 2013; Holyoak, 1984; Kahney, 1993; Klein, 1994; Kubricht et al., 2015; 2017; Lee, 1992; Ma, 2002; Zook, 1991).

It was, however, surprising to note that verbal analogical reasoning became a non-significant predictor of directed analogical transfer when entered into the same model as home language. This could simply indicate a technical issue within the analysis itself based on the specific parameters and sample; alternately it could potentially indicate that the two variables shared some form of common variance or relationship which negated the significance of verbal analogical reasoning as a predictor of directed analogical problem solving in the presence of home language. There is a degree of empirical evidence to support this proposition; previous research findings have identified significant links between verbal analogical reasoning and reading comprehension, vocabulary skills, and the ability to engage with complex language-based interpretations (Edwards et al., 2011; Jeong, 2009; Tabatabaee & Baghaei, 2018). Verbal analogical reasoning scores were also found to differ significantly on the basis of home language in the current study. Although entirely speculative, it is thus possible that this finding could point to the nature of the skills drawn on during the later stages of the analogical solution process, and that these represent an intersection of component abilities that underpin both verbal skill and verbal analogical reasoning skill. In contrast, the earlier stages of the analogical process, including representation and retrieval, have been shown to be less language dependent and may thus draw on more distinct abilities unique to each construct (Bernardo, 1998; Francis, 1999;

Fukumine & Kennison, 2016; Yanowitz, 2001). Although plausible, there appears to be no existing theory or evidence that directly supports this explanation; thus this interpretation must be treated with considerable caution and further work to establish the nature of the association between home language and verbal analogical reasoning, as well as their relative impact at different points in the analogical solution process, would be highly recommended. Despite this, the findings in the current study clearly point to the potential importance of both of these constructs in predicting analogical problem solving; this provides a useful base contribution from which to expand existing theory and interventions.

Both step-by-step/visualisation heuristic strategy preference and gender were significant predictors of directed analogical transfer but not of open analogical transfer in the sample; participants who indicated a higher level of preference for step-by-step/visualisation-based heuristic approaches and male participants were less likely to produce analogical solutions. This pattern was anticipated based on findings from the earlier analyses. For gender, the differential pattern observed could reflect aggregate male-female differences in task approach and level of processing of information; although the extent to which this is indicative of a consistent trend would need to be checked in different sample groups and contexts (Byrnes et al., 1999; Darley & Smith, 1995; Koenig, 2018; Meyers-Levy & Lokan, 2015; Pallier, 2003; Pichay et al., 2015; Severiens & ten Dam, 1994). Similarly, it is possible that a preference for approaching novel problems by focussing on either an entirely holistic interpretation or a highly deconstructed representation could obscure recognition of shared relational similarity, however this proposition requires further verification, including exploration of the link between preference and practice (Bailey et al., 2012; Pashler et al., 2008). In either case, the predictive role played by these variables appears to be more salient during the later stages of the analogical solving process such as mapping and adaptation, as the directed transfer task obviates the need for analogue retrieval (Barnett & Ceci, 2002; Day & Goldstone, 2012; Francis, 1999; Gick & Holyoak, 1983; Holyoak, 2012; Monaghan et al., 2015; Novick & Holyoak, 1991; Zook, 1991). Thus the findings in the current study offer interesting possibilities for furthering understanding of the different stages of the analogical problem solving process as well as the relationship between each of these variables and analogical problem solving generally.

Type of schooling and socioeconomic status significantly predicted open analogical problem solving but not directed analogical problem solving; this was not entirely anticipated based on the earlier analyses which indicated that socioeconomic status (SES) was associated with both forms of transfer in the sample. The reasons for this discrepancy could, however, be purely technical (possibly as a result of collinearity or margin of error); this

seems likely as one level of SES was significant for distinguishing between full and non-analogical solvers for the directed transfer task in the regression model despite SES not being a significant predictor overall. Nevertheless, the findings suggest that both of these variables, which also share an intrinsic relationship with one another that is especially evident in the South African context, are more closely linked to open analogical problem solving (Spaull, 2013a; Spaull, 2013b; van der Berg et al., 2011; Yamauchi, 2011). This implies that their role is particularly salient during the earlier stages of the analogical problem solving process such as recognition and retrieval; as obviating the need for these steps also appears to remove the potential significance of these variables as predictors. Socioeconomic status and type of schooling have links to a number of factors that could play an important part in shaping analogical solving capacity, including cognitive development, educational background, and previous exposure; the precise interplay between these remains as a critical area for further exploration though as research to date is highly limited (cf. Duncan & Magnuson, 2012; Farah, 2017; Hackman et al., 2010; Hackman et al., 2015; Ursache & Noble, 2016). As with gender and step-by-step/visualisation heuristic strategy preference, these findings offer interesting options for future investigation not only as regards their direct association with analogical problem solving, but also their potential for enhancing understandings of the different stages of the analogical transfer process.

Three of the predictor variables, non-verbal analogical reasoning, analogy heuristic strategy preference, and free production/combining heuristic strategy preference, did not significantly predict either directed or open analogical transfer across any of the regression models created. In the case of the heuristic strategy preference clusters, this was anticipated based on the earlier analyses – preference does not necessarily align with aptitude thus even if participants attempted to search for previous analogues or relevant problem elements with a view to combining these they may not have been able to successfully complete this process (Anolli et al., 2001; Bailey et al., 2012; Holyoak, 1984; Pashler et al., 2008; Thomas, 2008). In contrast, the failure of non-verbal analogical reasoning to act as a predictor was surprising given its association with both forms of transfer in the study. This outcome is particularly interesting when considered in light of the results obtained by Kubricht et al. (2017), who found that fluid intelligence, as measured by performance on an abridged version of the Raven's Progressive Matrices, was a significant predictor of spontaneous analogical transfer. In their study, however, their source analogue (which reflected the convergence schema) was based on the damage caused by firing different sizes and numbers of cannonballs at a central barrier – in two of their conditions this also included either a diagram or an animation. As such, Kubricht et al.'s (2017) source material was highly visual in nature whereas in the current study the source analogues used were

presented only in an enriched verbal format. This raises the possibility that the role played by non-verbal analogical reasoning in predicting analogical transfer may vary relative to the type of information contained in the source; in cases where this relies more heavily on visual elements or is more amenable to visual interpretation, non-verbal analogical reasoning capacity may become more salient. This also aligns fairly well with the proposed explanations for the relatively stronger relationship observed between verbal analogical reasoning performance and analogical transfer in the current study as opposed to non-verbal analogical reasoning and analogical transfer; distinctions in the underlying skills required to resolve each type of proportional analogy could also determine the efficacy with which the source analogue is understood which would impact all stages of the analogical problem solving process. Although tentative, these interpretations present a particularly interesting and potentially informative base for future study; a clearer understanding of the relative roles played by verbal and non-verbal analogical reasoning in successful analogical transfer across variant forms of analogues as regards modality could yield vital clues regarding the facilitation of analogical problem solving and schema formation.

One of the substantive advantages of the design adopted in the current study was the ability to identify predictors that spanned both forms of analogical problem solving and those that predicted only one or neither of the two forms. This represents an entirely novel area of exploration in the field; to date there appear to be no other studies that have directly compared different forms of analogical transfer and the relative roles played by other factors in relation to these. The findings from the current study thus represent an important preliminary contribution to enhancing understandings of the roles played by a number of key individual difference variables relative to analogical problem solving performance; this could form an important foundation for extending theory and developing interventions.

7.8. Overview: Key findings, implications, and contribution

The current study aimed to address a series of questions regarding the nature of the associations between analogical problem solving and different forms of analogical reasoning in a South African sample. More specifically, the focus of the study was to establish rates of directed and open analogical transfer and the nature of the relationship between these, as well as potential associative and predictive links between both forms of analogical problem solving and verbal and non-verbal analogical reasoning, various heuristic strategy preferences (including a preference for analogy), and several demographic variables. The analyses carried out to address these questions yielded a number of interesting and novel findings. The most important of these and their theoretical and practical implications are

summarised below; in conjunction with the discussion above these represent the contribution of the current study to existing knowledge and highlight its potential utility and originality.

Both the rate of spontaneous analogical transfer observed in the pilot sample and the rate of directed analogical transfer observed in the main sample were relatively low; these also appeared to be slightly lower than rates typically observed in international samples. This could simply represent an idiosyncratic set of outcomes stemming from the unique circumstances of the current study; for example, the less controlled nature of the administration of the task could have altered the way in which the source was engaged with or adherence to instructions. It is, however, also possible that these findings point to a more consistent pattern of differential analogical problem solving performance between South African samples and those obtained internationally. The extent to which this might be the case is impossible to estimate as to date there appear to be no other studies that have directly explored analogical transfer performance in the South African context. The possibility of this, however, highlights the critical need for further research on rates of analogical problem solving both locally (in South Africa) and across a wider range of international contexts and populations more generally. To date much of the theory and evidence available regarding analogical problem solving has been gathered in WEIRD (Westernised, educated, industrialised, rich, democratic) samples and contexts; although still important, this omits a critical mass of the human population as regards culture, ethnicity, language, and socioeconomic access (Henrich, Heine, & Norenzayan, 2010). It is thus vital to establish the extent to which similar patterns of performance and the theoretical understandings that stem from these hold true across a wider range of different cultures and contexts; in essence, this speaks to both applicability and universality. The power of this practice for enhancing existing theory can also be illustrated using the findings above; as these indicate that the rates of analogical problem solving observed in the sample were low in absolute terms as well as comparatively. This aligns perfectly with one of the most well established observations in the field of analogical problem solving, namely that it is difficult to enact effectively and occurs relatively rarely (cf. Antonietti et al., 2000; Billing, 2007; Cushen & Wiley, 2018; Gick & Holyoak, 1980; 1983; Izsof Jurasova et al., 2014; Kahney, 1993; Kaminski et al., 2013; Kubricht et al., 2017; Neuman & Schwarz, 1998; Novick & Holyoak, 1991; Thomas, 2008; Zook, 1991). The findings from the current study thus add to existing work through replication in a novel and diverse sample and context, and therefore can be seen as contributing meaningfully to knowledge expansion.

The open method of assessing analogical problem solving in the study led to the retrospective identification of five separate sets of relationally similar solution strategies that

could have been applied to the two analogues used. Although highly inferential in nature, this form of assessing transfer was thus successful in expanding the conceptualisation of what could constitute evidence of analogical problem solving; it also permitted participants to draw on a wider range of possible sources based on previous experience and was able to reflect transfer occurrence regardless of whether this was deliberate or implicit. As such, the method appeared to capture a more realistic solution process and was able to address several critiques raised regarding the traditional approach as too narrow, too restricted in scope, and too reliant on pre-defined conceptualisations of analogical transfer (cf. Anolli et al., 2001; Blanchette, 2000; Chen et al., 2004; Day & Goldstone, 2012; Gentner & Smith, 2012; Holyoak, 2012; Lave, 1998; Lee, 1992; Lobato, 2006; Nokes, 2009; Novick & Holyoak, 1991; Trench & Minervino, 2015; Wedman et al., 1996). It is important to acknowledge that there were also several key limitations to the method, including an inability to guarantee access to a source and questions regarding the level of analogical intent of the participant. Despite this, the method represents an interesting and novel hybrid; a form of assessment of analogical problem solving that sits somewhere between the more controlled laboratory approach and everyday observation. As such, it could function as an important bridging mechanism to resolve current tensions between experimental and naturalistic findings in the field (cf. Bearman et al., 2002; Blanchette, 2000; Day & Goldstone, 2012; Holyoak, 2012; Trench & Minervino, 2015); it could also provide unique insights into the frequency and difficulty of analogical problem solving to augment existing theory. The various similarities and differences in patterns of results obtained across the two forms of transfer in the remainder of the analyses also served to highlight the utility of the method as a way in which to cross-validate and triangulate findings and identify critical differences at different points of the analogical solution process.

A significant and positive albeit weak association was established between rates of directed and open analogical transfer in the sample; this provided preliminary evidence supporting analogical problem solving as a relatively stable skill in young adults. To date there appear to be no other studies that have contrasted different forms of analogical problem solving in the same sample of participants, thus this finding made a useful empirical contribution to existing theory. It also pointed to the potential value of identifying participants who either succeeded in solving both tasks analogically or who failed to do so completely and thus demonstrated relatively consistent analogical problem solving performance under variant conditions of assessment. These groups appear to represent relatively stable extremes of analogical problem solving skill and could thus provide invaluable insight into the characteristics and behaviours associated with analogical transfer success or failure.

The overall pattern of findings obtained regarding the associations between directed and open analogical transfer and verbal and non-verbal analogical reasoning in the sample suggested that analogical problem solving and analogical reasoning were significantly and positively related to one another, however this relationship was relatively weak in nature. This outcome clearly supports the existence of both shared components and critical distinctions between these two constructs as regards scope, process, and underlying skills (Goswami, 1991; Holyoak, 1984; 2012; Kahney, 1993; Novick & Holyoak, 1991). As such, it adds substantively to current knowledge, not only in terms of expanding the body of empirical evidence available, but also as a means of reconciling existing theoretical tensions and conflicting results. The findings also unequivocally indicate the need for analogical problem solving and analogical reasoning to be regarded and treated as distinct constructs and negate suggestions that these two activities represent superficially variant manifestations of the same underlying ability (cf. Abdellatif et al., 2008; Barnett & Ceci, 2002; Embretson & Schneider, 1989; Goswami, 1991; Holyoak, 1984; Kahney, 1993; Morrison, 2004; Zook, 1991). This has critical implications for interpretation of the extant literature; theory and findings regarding either phenomenon should not simply be transposed or treated as interchangeable unless there is evidence to support their shared relevance.

Although the results yielded by the comparison tests indicated that both verbal and non-verbal analogical reasoning scores differed significantly on the basis of analogical transfer success, the associative tests indicated that non-verbal analogical reasoning was only significantly related to open transfer. These analyses also indicated that there were relatively stronger associations between verbal analogical reasoning and analogical problem solving than there were between non-verbal analogical reasoning and analogical problem solving in the sample. In addition, non-verbal analogical reasoning did not significantly predict either directed or open analogical transfer in the regression models whereas verbal analogical reasoning significantly predicted both forms of transfer. This pattern of findings implies that the interplay between analogical problem solving and analogical reasoning is complex in nature and may shift in form relative to task type and cognitive demand. Thus, for example, the successful extraction of shared relational elements and solution strategies between verbally-based analogues may be more reliant on component skills that also underpin the successful resolution of verbal proportional analogies relative to those that inform successful figural proportional analogy resolution. Furthermore, the extent to which these shared underlying skills become salient may vary across different stages of the analogical solution process; this could account for the slightly stronger association between non-verbal analogical reasoning and open transfer observed in the sample. Taken together, these interpretations could point to a potential way in which to reconcile the contradictory

empirical outcomes reported in the extant literature; they also highlight the importance of considering and comparing types of analogical reasoning tasks and variant analogues when attempting to establish an associative pattern between the two constructs. To date, there appear to be no other studies that have directly compared analogical reasoning performance across different types of proportional analogies with different forms of analogical problem solving in the same sample of participants; as such, this element of the study provided a novel contribution to existing theory with potentially important practical implications for future research.

The regression analyses also showed that verbal analogical reasoning was a consistent predictor of analogical problem solving except when entered into the same equation as home language with directed analogical transfer as the outcome variable. This finding illustrates the potential utility of exploring and comparing the predictive roles played by individual difference variables across variant forms of analogical problem solving, as the outcome obtained suggested that intersecting component skills shared between home language verbal ability and verbal analogical reasoning ability played a more salient role in the later stages of the analogical problem solving process. This result, as well as this type of exploration more generally, could thus contribute substantively to the development of increasingly refined understandings of the different stages of analogical problem solving, as well as the interplay between individual characteristics of the problem solver and the steps involved in successful analogical transfer.

To date, there appear to be no previous studies that have explored the potential links between habitual problem solving style and analogical problem solving; as such, this study produced primary empirical evidence regarding the nature of the associations between variant self-reported heuristic strategy preferences and both directed and open analogical transfer. Although some form of relationship was anticipated, the findings in the study indicated that a preference for using analogy as a heuristic approach was not associated with or predictive of analogical problem solving. This outcome is important for instructional and facilitative practice, as it suggests that neither a simple directive to consider previous analogues nor an intention to do so is sufficient to generate a successful analogical resolution to a novel problem. The results also indicated that a preference for adopting step-by-step and visualisation-based heuristic strategies impeded directed analogical transfer but not open analogical transfer; this suggests that an inclination towards insight-based (holistic) or sequential (compartmentalised) heuristic strategies may interfere with successful mapping and adaptation. This outcome not only adds to existing theory, but also supports the potential utility of instructional practices such as enhanced metacognitive awareness and

strategy-switching for facilitating analogical transfer and schema formation (cf. Billing, 2007; Brown & Clement, 1989; Richland & Simms, 2015; Vendetti et al., 2015). Furthermore, the results showed that successful analogical problem solving for both task types was linked to a preference for discarding irrelevant information. This finding not only highlights the importance of fostering methods for adjudicating relevance as a key component of enhancing analogical problem solving success, it also points to the value of exploring the links between analogical transfer and individual difference factors such as field independence and selective attention (cf. Antonietti & Gioletta, 1995; Cushen, 2012; Cushen & Wiley, 2018). Taken together, the outcomes of the analyses exploring the links between heuristic strategy preference and analogical problem solving proved particularly valuable for identifying practical approaches that could be successful in facilitating analogical transfer and schema development; as such, this line of inquiry appears to be a useful contribution to the extant literature both in terms of the current findings and as a path for further study.

The potential links between analogical problem solving and four demographic variables – gender, home language, type of schooling, and socioeconomic status – were also considered in the study; the results indicated that all of these were significantly associated with and/or predictive of at least one form of analogical problem solving (either directed or open or both). This set of findings reinforces the importance of considerations of universality of theory and the necessity of carrying out further research in more varied and representative samples. With regards to gender, the outcomes in the current study indicated an interesting inversion of previous trends – males performed less well than females for the directed transfer task but similarly for the open transfer task. This finding has potential implications for both existing beliefs and changing dynamics regarding gender roles and stereotypes, although the extent to which it represents a more consistent pattern would first need to be established. Similarly, the findings regarding home language could have meaningful implications for educational practice, including policies regarding language of instruction (Saarinen, 2017; Francis, 1999; Fukumine & Kennison, 2016; Yanowitz, 2001), however a clearer picture of differential performance across more variant language groups would first need to be established. Despite the clear importance and relevance of analogical problem solving in the educational sphere and consistent trends linking socioeconomic status and cognitive skills development (cf. Duncan & Magnuson, 2012; Farah, 2017; Hackman et al., 2010; Hackman et al., 2015; Richland & Burchinal, 2013; Simms et al., 2018; Ursache & Noble, 2016; von Stumm & Plomin, 2015), to date there appear to be no previous studies that have explored the links between these two variables and analogical problem solving. The findings from the current study thus represent critical preliminary evidence pointing to the need to further explore the connections between analogical problem

solving and these particular demographic variables; this could make an important contribution to both theory development and schema facilitation.

As is evident from the discussion above, the current study represented a large number of 'firsts' in that no previous empirical work of a directly similar kind could be sourced. More specifically, the current study appears to be the first to explore analogical problem solving in a South African sample and context, the first to utilise an 'open' method of assessing transfer, and the first to directly compare two different estimates of analogical problem solving capacity in the same sample assessed using distinct methods. The current study was also the first to directly compare the relative roles played by two different forms of analogical reasoning capacity as regards their relationship to and prediction of analogical problem solving; and the first to employ more advanced measures to capture these constructs. The study was the first to assess the association between analogical problem solving and heuristic strategy preference, including a preference for utilising analogy as a heuristic, the first to consider modal preference in relation to analogical problem solving, and the first to explore the predictive role played by these variables in determining analogical transfer success. The study was also the first to consider the potential links between gender and home language and analogical problem solving in the South African context, and the first to consider the potential role played by socioeconomic status and type of schooling both locally and internationally. The predictive models created in the current study were also unique, containing a mix of predictors that do not appear to have been considered previously. In addition, the study was the first to attempt a formal validation of a measure to assess habitual problem solving style (as assessed by heuristic strategy preference). Based on this extensive list, it seems very reasonable to argue that the current study was in a position to make a small yet substantive and original contribution to existing knowledge in the field of analogical problem solving. In addition, the findings of the study suggested a considerable number of possibilities for further development, refinement, and enhancement of existing theory moving forward; these too represent a significant contribution to building further understanding and advancing knowledge.

7.9. Overview: Limitations

Despite its contribution to existing knowledge, there are a number of limitations of the current study that merit acknowledgement; a clearer understanding of these is also necessary to appropriately contextualise the findings yielded by the analyses and the proposed implications of these.

Although relatively large and comparable in nature to samples used in international studies, the sample in the current study was nevertheless limited in its ability to adequately represent the general population in a number of important ways. Firstly all of the participants sourced for the study were university students; by definition, this group represents a distinct and fairly elite sub-population, particularly as regards level of education, acculturation, urbanisation, and previous exposure to research. Although the subject forms a part of different paths of study and degrees, the sample was also drawn only from students registered for Psychology. This could have further restricted the range of characteristics represented in the sample group and potentially excluded particular sub-groups of students with distinct characteristics and aptitudes that may have altered the nature of the findings. The decision to use university students was motivated by the need to obtain participants with reasonably high levels of English fluency and familiarity with formal testing; although essential for the administration of the measures these requirements further restricted the representativeness of the sample, particularly in relation to the general South African population. The sampling strategy employed was also non-probability, haphazard, and convenience-based in nature, thus the sample was limited further as it was not necessarily even representative of every element in the accessible population (students registered for Psychology at the University of the Witwatersrand), much less the wider student population or general population (Laher, 2016; Rosenthal & Rosnow, 2008; Salkind, 2006).

The sample consisted of volunteers, which could raise concerns regarding volunteer bias, for example, participants may have been more altruistic, higher in their need for approval, more sociable, less conventional, and more open than those in the population who chose not to participate (Laher, 2016; Rosenthal & Rosnow, 2008; 2009; Stangor, 2015; Tredoux & Smith, 2006). It is important to note, however, that this possibility was countered to an extent by the use of motivational strategies; it is very likely that a wider range of potential participants chose to take part in the study as a result of the tangible rewards offered for doing so. This proposition is supported by the unusually high response rate (approximately eighty percent) that was observed in the main study. The sample size itself was also much larger than that typically obtained for studies in the field which improved generalisability to an extent. There were, however, a disproportionate number of females and English home-language speakers in the main sample and the number of other home languages and the level of detail captured regarding type of schooling was limited. These latter issues necessitated the combination of certain categories for the analyses which could have obscured important variations. In addition, the categories for socioeconomic status were artificially created based on the range in the sample itself; although it was felt that these were still reasonably representative of real-world distinctions in the South African

student population this could nevertheless have altered the outcomes obtained. As a whole, the disproportionate numbers of participants across certain categories and the subsequent collapsing of certain of these could have affected both the homogeneity of the individual demographic groupings used and their ability to appropriately reflect the broader population.

Other limitations in the study pertained to the instruments used and the measurement of the key variables as well as their administration; these represented potentially critical issues as effective numerical representation of the constructs lies at the heart of quantitative research and fundamentally determines the quality of the analyses and results obtained (Babbie & Mouton, 2001; Laher, 2016; Murphy & Davidshofer, 2005; Rosenthal & Rosnow, 2008; Salkind, 2006; Stangor, 2015). The *directed analogical transfer task* was originally designed as a measure of spontaneous analogical transfer, however the analogical response rate observed in the pilot study was so low that it necessitated the provision of a hint regarding the relevance of the source passage in order to ensure the viability of the study as a whole – this shifted the task to one assessing directed analogical transfer. The method of administration of the task was not comparable to most previous studies in the field, though, as both the source and the target analogues were presented to participants in written form as part of a larger questionnaire pack that could be completed in their own time. This was far less controlled than the typical timed presentation process; as such, it is difficult to estimate potential variations in level of engagement with the source although the comprehension questions posed did serve as a partial check regarding this. Nevertheless, the amount of time spent on the source analogue was not standardised, acquisition of the source strategy was not guaranteed, and participants could have ignored or failed to adequately process the instructions for the target problem, including the hint regarding relevance. It is also impossible to rule out potential effects stemming from prior exposure to the example analogue and knowledge of the solution strategy, although the low rate of analogical transfer obtained suggests this was unlikely to be a substantive issue in the study. The failure of certain principles for improving rates of analogical transfer that were worked into the source such as the provision of two exemplars, the comprehension questions to encourage retrieval practice and comparison, and the embedded hint regarding analogical processing, was also surprising (cf. Catrambone & Holyoak, 1989; Chen & Mo, 2004; Edwards et al., 2014; Gick & Holyoak, 1983; Gick & Paterson, 1992; Hostetter et al., 2018; Novick & Holyoak, 1991; Peterson & Wissman, 2018; Reeves & Weisberg, 1994; Richland & McDonough, 2010).

The *open analogical transfer task* represented a highly novel approach to the assessment of analogical problem solving and was effective in addressing certain concerns

raised regarding the traditional investigative paradigm (cf. Anolli et al., 2001; Blanchette, 2000; Chen et al., 2004; Day & Goldstone, 2012; Gentner & Smith, 2012; Holyoak, 2012; Lave, 1998; Lee, 1992; Lobato, 2006; Nokes, 2009; Novick & Holyoak, 1991; Trench & Minervino, 2015). The scoring for the task was, however, retrospective and highly inferential; this raises a potential critique regarding the extent to which observed relational similarities in the solutions presented were representative of actual analogical transfer as opposed to accidental or coincidental. Another concern raised pertains to the potential for observing analogical transfer; although the method appeared to capture a wider range of analogical solution strategy sets it did not guarantee that an analogical source was known to the participant in the first instance. Thus it was not possible to distinguish between a failure of analogical transfer that arose from a lack of recognition of the relevance of a source and a failure that arose from a lack of a suitable source altogether. The popularity of the analogues used in the open transfer task represented another potential issue – both of these are fairly well known which increased the potential for individually developed solutions rather than solution strategies created through an analogical process. It is, however, important to consider that this could represent a more implicit form of analogical transfer in and of itself, which could thus speak to an advantage of the method rather than a disadvantage.

The measures used to assess verbal analogical reasoning and heuristic strategy preference were both self-developed as suitable pre-existing scales could not be sourced. The *verbal analogical reasoning task* was designed to reflect a range of verbal proportional analogy types; all content was also carefully reviewed for any evidence of potential cultural bias and exemplars that were deemed to require a high level of familiarity with nuances in English or Westernised conventions were excluded. Although this worked well to reduce potential instrument bias, it also appeared to have the unintended effect of making the items in the scale relatively easy as the scores were generally high and exhibited ceiling effects (Salkind, 2010). The results of the factor analysis also made it clear that the original pool of items measured different underlying factors rather than a single ability; this necessitated omitting eleven items and further reduced the range of scores slightly. Even with this reduction, which did enhance the validity of the scale as all the remaining items loaded acceptably onto a single factor, the internal consistency reliability of the measure remained low (Murphy & Davidshofer, 2005). The *self-reported heuristic strategy preference measure* also did not function as originally intended; the underlying factors identified represented a different pattern of combinations for heuristic strategies from those theorised based on the literature (Antonietti et al., 2000; Güss & Wiley, 2007; Metallidou & Platsidou, 2008). Although this was a useful and important potential contribution to knowledge in its own right, two of the new strategy clusters had low internal consistency reliabilities and one cluster had

to be discarded altogether as the internal consistency reliability was below an acceptable standard (although the items were retained for individual analysis). Thus although both measures were adequate and sufficient for the study they were also less than ideal for capturing the constructs of interest.

Although fairly straightforward, the process of administering the measures also raised certain potential issues and limitations. One of the most important of these was the time required for participation in the study; in total, this averaged approximately an hour-and-a-half to two hours, which is a substantial time commitment by any standard. Despite the checks in the pilot study and the incentives offered, particularly the course credit in the main study, the potential for response biases based on time effects, boredom, and fatigue such as random responding, dissimulation, and logical error in rating thus remained very high (Murphy & Davidshofer, 2005). The use of incentives, although helpful in increasing the sample size, could have also elicited certain response biases and altered the way in which participants responded to the questionnaire pack (Cozby & Bates, 2012; Rosenthal & Rosnow, 2008; 2009; Stangor, 2015). Another potential issue pertained to independence; although a majority of pilot participants indicated that they followed instructions to complete the questionnaire pack on their own without external input, there was no way to guarantee that participants adhered to this request. As such, their responses may have reflected input from other people or reference material. The extent to which participants fully understood and followed the instructions given for each task was also a potential concern, although the results from the pilot study and lack of queries directed to the researcher during the administration suggested this was not particularly problematic. The order in which participants completed the questionnaires could have also created a potential confound as regards utilising analogy as a heuristic approach, although the rates of analogical transfer obtained suggest this was unlikely to be a substantive issue in the study.

With regards to the analyses conducted, the data yielded from the analogical problem solving measures as well as a number of the demographic variables were categorical in nature (Howell, 2013). The scores for the *verbal analogical reasoning task* were also skewed, which necessitated a conversion to categorical form for certain of the analyses. The nature of these variables restricted the scope of the potential analyses that could be applied to the data to a fairly large extent; as such, the analyses used to address the research questions were relatively simple techniques and, for the most part, univariate in nature (Howell, 2013). It is important to note that the techniques chosen were suitable to address the questions posed, appropriate given the qualities of the data, and reported as accurately as possible; sophistication is also not a guarantee of improved analytic quality.

Nevertheless, the utilisation of multiple simpler techniques could raise certain technical concerns regarding spuriousness and the scope of the questions that could be addressed was also slightly limited (Howell, 2013). All of the effect sizes calculated were also small in nature; this suggests that the practical significance of the findings could be quite limited, although it must be noted that there are no guidelines for anticipated ranges of effect sizes in this particular area of study which could change the interpretation of the values obtained (cf. Biddix, 2016; Coe, 2002; Lipsey et al., 2012).

The design of the study was quantitative, non-experimental, correlational, and cross-sectional; this design carries with it a number of recognised limitations (Cozby & Bates, 2012; Leedy & Ormrod, 2005; Neuman, 2010; Rosenthal & Rosnow, 2008; Salkind, 2006; Stangor, 2015). By definition, non-experimental correlational studies contain very few if any features that allow for causality to be established; this typically includes no manipulation of the independent variable, an absence of strict control groups, and no random assignment (Cozby & Bates, 2012; Leedy & Ormrod, 2005; Rosenthal & Rosnow, 2008; Salkind, 2006; Stangor, 2015). As such, the nature of the conclusions that can be drawn are associative at best; and it is not possible to establish clear directionality or rule out the potential role played by other cross-associated or extraneous variables (Cozby & Bates, 2012; Leedy & Ormrod, 2005; Rosenthal & Rosnow, 2008; Salkind, 2006; Stangor, 2015). The cross-sectional nature of the design also limits the scope of observation to a single point in time, thus longitudinal effects are not able to be established and potential variations in participant behaviour over even relatively short timeframes are typically not accounted for (Cozby & Bates, 2012; Leedy & Ormrod, 2005; Rosenthal & Rosnow, 2008; Salkind, 2006; Stangor, 2015). Quantitative research also rests on the process of quantification, the conversion of data to numerical form through measurement (Durrheim, 1999). Although economical, practical, and much better suited to comparative purposes, quantification can also lead to a loss of substance and authenticity, as well as issues regarding objectification, depth, and relevance (Babbie & Mouton, 2001; Durrheim, 1999; Murphy & Davidshofer, 2005). The underlying ontological and epistemological implications of adopting a quantitative approach are also often disregarded, although an effort has been made to acknowledge certain of these when framing the findings from the current study (Stangor, 2015; Terre Blanche & Durrheim, 2006; Trochim, 2006).

7.10. Overview: Future directions

Both the limitations and the implications identified in the study raise a number of interesting and important possibilities for further empirical work in the field of analogical

problem solving. These not only represent ways in which to expand and enhance understanding but also epitomise a key contribution of the current study in terms of its potential to function as a foundation from which to build and extend original future lines of enquiry in a vital and under-explored area.

The outcomes obtained in the current study clearly emphasise the need for additional work that explores the phenomenon of analogical problem solving in the South African context, including research that focusses on establishing rates of spontaneous and directed analogical transfer using the traditional investigative paradigm for comparative purposes. Further studies with a range of sample groups and using variant analogue pairs and types would also be highly recommended, as would the implementation of experimental approaches to establish if international patterns are replicated with regards to schema development and setting effects. The South African context also provides a unique milieu in which to explore the potential associative and predictive links between analogical problem solving and a range of demographic variables. Further work along these lines would thus also be highly recommended, particularly studies focussed on a clearer understanding of the nature of the associations between analogical transfer and factors such as gender, home language, socioeconomic status, and type of schooling; this could have important implications for both theory development and instructional practice. It would also be useful if the scope of these variables could be extended in future research to encompass a wider range of categories; this could include obtaining larger sample sizes as well as utilising more sophisticated measures to capture more nuanced representations of gender, home language, socioeconomic status, and schooling background. It is also worth noting that the value of this type of investigation is not limited to the South African context; the importance of additional studies exploring analogical problem solving and the interplay between context, demographics, and analogical transfer across a range of variant cultures and countries is also highlighted by the current research. This type of work would have important implications for cross-cultural application and confidence as regards the universality of the extant theory.

The findings from the current study also underscore the value of a comparative framework that encompasses different overt forms of analogical problem solving for building towards more flexible and complete nomothetic understandings. Additional work that focuses on triangulating analogical transfer performance across different types of analogical problem solving tasks would thus be highly recommended; including studies that adopt creative forms of assessment that seek to address concerns raised regarding the traditional investigative paradigm and conflicts suggested by more naturalistic work. This type of bridging research could be useful for extending understandings of the different stages of the analogical transfer

process, especially the critical role played by retrieval. It could also prove especially valuable as a mechanism for improving understandings of analogical transfer success and failure through the identification of sample groups that demonstrate relatively stable analogical problem solving skills across variant assessments. Identifying the unique sets of characteristics shared by these groups could lead to new insights regarding factors that facilitate and hinder transfer; this, in turn, could form the base for novel methods to encourage schema development, learning, creativity, and innovation and could thus be of immense value. Additional applications of the open method of transfer could also be extremely useful to enhance existing theory. For example, if this method is paired with think-aloud solution protocols it could provide unparalleled insight into the extent to which analogical problem solving occurs as a conscious and deliberate activity as well as the retrieval process when analogues are drawn from long-term memory. It would also be extremely interesting to investigate similarities and discrepancies in rates of transfer produced by open and spontaneous methods in the same sample; this could be especially helpful for furthering understandings of the processes involved in representation and retrieval.

A primary focus of the current study was to explore the nature of the association between analogical problem solving and analogical reasoning; this was motivated by the contradictory results obtained regarding this relationship in previous work. Additional research across diverse samples that could serve as a form of verification for the findings in the current study would thus be extremely useful; as would further work utilising a more established measure of verbal analogical reasoning. Comparative studies exploring the links between both verbal and non-verbal analogical reasoning and different forms of analogical transfer would also be highly recommended; based on the current findings, this should include using analogues with variant levels of transparency, familiarity, and similarity, as well as those reliant on and amenable to different modalities. Although beyond the scope of the current study, the extent to which different types of proportional analogies reflect the same underlying capability as opposed to unique skill sets could also be an interesting and important direction for future research; empirical investigation of this question is highly limited despite the widespread assumption that resolution of all proportional analogy types rests on a core underlying skill to reason analogically.

Another focal area in the study was to explore the relationships between self-reported heuristic strategy preference and analogical problem solving; this set of findings proved particularly useful for identifying potential pragmatic approaches to facilitate analogical transfer. Further experimental work to verify the utility of these methods as well as

additional exploratory work to identify links between habitual solving problem style and analogical problem solving success would thus be highly recommended. Additional psychometric studies to develop and refine instrumentation to assess heuristic preference and habitual problem solving style in a range of contexts would also be strongly warranted; as would additional correlational research to explore links between analogical problem solving and factors associated with certain of the strategies such as field independence and selective attention/ focus.

The regression models established in the study point to the value of considering the interplay between different individual difference factors in predicting analogical transfer; this extends to studies that explore the relative predictive roles played by process factors and individual difference factors as well. Further research to identify new predictive models and establish the stability of those already created across different samples and contexts would thus be highly recommended; as would additional studies using large sample groups and non-experimental methods (i.e. measurement only) as an important adjunct to the larger body of experimental work available. Further work employing qualitative methods of investigation could also be useful to augment available understandings of the analogical transfer process as well as the extent to which analogy is utilised and in what forms in real-world occupational and educational settings. This could also help to identify links between previous experiences with analogy such as its perceived efficacy as a method of instruction in the classroom and the later use of analogy as a successful problem solving strategy.

7.11. Conclusion

The broad aim of the current study was to explore the associations between analogical problem solving and different forms of analogical reasoning. More specifically, the study examined rates of directed and open analogical transfer, the association between these, and the associative and predictive links between these and verbal and non-verbal analogical reasoning, preference for analogy as a heuristic strategy, other forms of heuristic strategy preference, and several demographic variables (gender, home language, socioeconomic status, and type of schooling). Despite a number of limitations, the findings from the study served to address a number of novel and interesting research questions, many of which had not been considered previously. The implications raised by these findings formed a unique set of interpretations that are in a position to augment existing theory and serve as a base for creative and innovative directions for future work in the field.

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Appendices

Appendix A

Convergence schema analogues from Gick and Holyoak (1980)

The general.

A small country fell under the iron rule of a dictator. The dictator ruled the country from a strong fortress. The fortress was situated in the middle of the country, surrounded by farms and villages. Many roads radiated outward from the fortress like spokes on a wheel. A great general arose who raised a large army at the border and vowed to capture the fortress and free the country of the dictator. The general knew that if his entire army could attack the fortress at once it could be captured. His troops were poised at the head of one of the roads leading to the fortress, ready to attack. However, a spy brought the general a disturbing report. The ruthless dictator had planted mines on each of the roads. The mines were set so that small bodies of men could pass over them safely, since the dictator needed to be able to move troops and workers to and from the fortress. However, any large force would detonate the mines. Not only would this blow up the road and render it impassable, but the dictator would then destroy many villages in retaliation. A full-scale direct attack on the fortress therefore appeared impossible. The general, however, was undaunted. He divided his army up into small groups and dispatched each group to the head of a different road. When all was ready he gave the signal, and each group charged down a different road. All of the small groups passed safely over the mines, and the army then attacked the fortress in full strength. In this way, the general was able to capture the fortress and overthrow the dictator.

The radiation problem.

Suppose you are a doctor faced with a patient who has a malignant tumor in his stomach. It is impossible to operate on the patient, but unless the tumor is destroyed the patient will die. There is a kind of ray that can be used to destroy the tumor. If the rays reach the tumor all at once at a sufficiently high intensity, the tumor will be destroyed. Unfortunately, at this intensity the healthy tissue that the rays pass through on the way to the tumor will also be destroyed. At lower intensities the rays are harmless to healthy tissue, but they will not affect the tumor either. What type of procedure might be used to destroy the tumor with the rays, and at the same time avoid destroying the healthy tissue?

Convergence schema analogues from Gick and Holyoak (1983)

The general.

A small country was ruled from a strong fortress by a dictator. The fortress was situated in the middle of the country, surrounded by farms and villages. Many roads led to the fortress through the countryside. A rebel general vowed to capture the fortress. The general knew that an attack by his entire army would capture the fortress. He gathered his army at the head of one of the roads, ready to launch a full-scale direct attack. However, the general then learned that the dictator had planted mines on each of the roads. The mines were set so that small bodies of men could pass over them safely, since the dictator needed to move his troops and workers to and from the fortress. However, any large force would detonate the mines. Not only would this blow up the road, but it would also destroy many neighboring villages. It therefore seemed impossible to capture the fortress. However, the general devised a simple plan. He divided his army into small groups and dispatched each group to the head of a different road. When all was ready he gave the signal and each group marched down a different road. Each group continued down its road to the fortress so that the entire army arrived together at the fortress at the same time. In this way, the general captured the fortress and overthrew the dictator.

The commander.

A military government was established after the elected government was toppled in a coup. The military imposed martial law and abolished all civil liberties. A tank commander and his forces remained loyal to the overthrown civilian government. They hid in a forest waiting for a chance to launch a counterattack. The commander felt he could succeed if only the military headquarters could be captured. The headquarters was located on a heavily guarded island situated in the center of a lake. The only way to reach the island was by way of several pontoon bridges that connected it to the surrounding area. However, each bridge was so narrow and unstable that only a few tanks could cross at once. Such a small force would easily be repulsed by the defending troops. The headquarters therefore appeared invincible. However, the tank commander tried an unexpected tactic. He secretly sent a number of tanks to locations near each bridge leading to the island. Then under cover of darkness the attack was launched simultaneously across each bridge. All of the groups of tanks arrived on the island together and immediately converged on the military headquarters. They managed to capture the headquarters and eventually restore the civilian government.

Red Adair.

An oil well in Saudi Arabia exploded and caught fire. The result was a blazing inferno that consumed an enormous quantity of oil each day. After initial efforts to extinguish it failed, famed firefighter Red Adair was called in. Red knew that the fire could be put out if a huge amount of fire retardant foam could be dumped on the base of the well. There was enough foam available at the site to do the job. However, there was no hose large enough to put all the foam on the fire fast enough. The small hoses that were available could not shoot the foam quickly enough to do any good. It looked like there would have to be a costly delay before a serious attempt could be made. However, Red Adair knew just what to do. He stationed men in a circle all around the fire, with all of the available small hoses. When everyone was ready all of the hoses were opened up and foam was directed at the fire from all directions. In this way a huge amount of foam quickly struck the source of the fire. The blaze was extinguished, and the Saudis were satisfied that Red had earned his three million dollar fee.

The fire chief.

One night a fire broke out in a wood shed full of timber on Mr. Johnson's place. As soon as he saw flames he sounded the alarm, and within minutes dozens of neighbors were on the scene armed with buckets. The shed was already burning fiercely, and everyone was afraid that if it wasn't controlled quickly the house would go up next. Fortunately, the shed was right beside a lake, so there was plenty of water available. If a large volume of water could hit the fire at the same time, it would be extinguished. But with only small buckets to work with, it was hard to make any headway. The fire seemed to evaporate each bucket of water before it hit the wood. It looked like the house was doomed. Just then the fire chief arrived. He immediately took charge and organized everyone. He had everyone fill their bucket and then wait in a circle surrounding the burning shed. As soon as the last man was prepared, the chief gave a shout and everyone threw their bucket of water at the fire. The force of all the water together dampened the fire right down, and it was quickly brought under control. Mr. Johnson was relieved that his house was saved, and the village council voted the fire chief a raise in pay.

The radiation problem.

Suppose you are a doctor faced with a patient who has a malignant tumor in his stomach. It is impossible to operate on the patient, but unless the tumor is destroyed the patient will die. There is a kind of ray that can be used to destroy the tumor. If the rays reach the tumor all at once at a sufficiently high intensity, the tumor will be destroyed. Unfortunately, at this intensity the healthy tissue that the rays pass through on the way to the tumor will also be destroyed. At lower intensities the rays are harm- less to healthy tissue,

but they will not affect the tumor either. What type of procedure might be used to destroy the tumor with the rays, and at the same time avoid destroying the healthy tissue?

Convergence schema analogues from Catrambone and Holyoak (1989)

The radiation problem (dosage version).

Suppose you are a doctor faced with the following problem. A malignant tumor has developed in the stomach of one of your patients. If the tumor is not treated soon, the cancer will spread throughout the patient's body, resulting in death. Because of some medical complication it is impossible to perform an operation to remove the tumor or restrict its blood supply. There is therefore no simple way to treat the patient's condition. However, you have available a kind of ray that can be used to destroy the tumor. A sustained large dose of the rays will effectively destroy the tumor. Unfortunately, at this dosage the rays will also destroy the healthy tissue that they pass through on the way to the tumor. At a lesser dosage the rays would not harm the healthy tissue, but they would not destroy the tumor either. What type of procedure might be used to destroy the tumor with the rays, and at the same time avoid destroying the healthy tissue? Suggest as many possible solutions as you can. Write down all the possibilities you can think of, even ones that may not really be practical. Don't worry about not having enough medical knowledge. Use any information you can think of to help solve the problem.

The aquarium.

A major aquarium in a city on the East Coast decided to create a large aquarium display containing a replica of the sunken ocean liner the Titanic amid the sea environment of its resting place, which is deep in the Atlantic Ocean off the coast of Newfoundland. A professional aquarium designer was assigned to the project. She placed a small replica of the vessel in the center of a large tank, with a realistic sea bed. Then she added to the tank sea plants and fish of the sort that live in the Atlantic at the depth of the sunken Titanic. The display was virtually finished when the designer was confronted with a major problem she had failed to anticipate. In order to maintain the deep-water environment required by the fish and plants, the tank had to be kept quite dark, as the deep-water organisms were not adapted to light. However, if the tank was kept completely dark, people would not be able to see the small replica of the Titanic in the center of the tank, which, after all, was the main point of the exhibit. Putting lights inside the model of the wreck looked too artificial. The designer considered shining a powerful spotlight on the model of the vessel. However, if the spotlight was located inside the tank, it would raise the temperature of the water too high; and if it was located outside the tank, the bright beam seriously disrupted the feeding habits of some of the fish. So it looked like the display was going to have an embarrassing shortcoming. What could be done to light the display? Write your solution below. Remember to use the same principles that were used in the stories you read.

Convergence schema analogues from Corkill and Fager (1995)

The surgeon (less familiar source).

A patient has been complaining about stomach problems for a considerable period of time. A number of tests are run and it is discovered that the patient has a malignant tumor in his stomach. Suppose you are the specialist called in to treat this patient. You know that it is impossible to operate on the patient, but unless the tumor is destroyed the patient will die. There is, however, a kind of ray that can be used to destroy the tumor. If the ray reaches the tumor at a sufficiently high intensity, the tumor will be destroyed. Unfortunately, at this intensity the healthy tissue that the ray passes through on the way to the tumor will also be destroyed. At lower intensities the ray is harmless to healthy tissue, but it will not affect the tumor either. A full intensity dosage of the ray appeared impossible. The specialist, however, was undaunted. She divided the ray into a larger number of lower intensity rays and positioned them at multiple locations around the patient's body. All of the lower-intensity rays

passed harmlessly through the healthy tissue and converged on the tumor at full strength. In this way, the specialist was able to destroy the tumor and save the patient's life.

The general (familiar source).

A small country was ruled from a strong fortress by a dictator. The fortress was situated in the middle of the country, surrounded by farms and villages. Many roads lead to the fortress through the countryside. Suppose you are a rebel general who has vowed to capture the fortress. You know that an attack by your entire army would capture the fortress. So you gather your army at the head of one of the roads, ready to launch a full-scale direct attack. However, you then learn that the dictator has planted mines on each of the roads. The mines were set so that small groups of people could pass over them safely, since the dictator needed to move his troops and workers to and from the fortress. However, a large force would detonate the mines. Not only would this blow up the road, but it would also destroy many neighboring villages. It therefore seemed impossible to capture the fortress. The general, however, devised a simple plan. He divided his army into small groups and dispatched each group to the head of a different road. When all was ready he gave the signal and each group marched down a different road. Each group continued down its road to the fortress so that the entire army arrived together at the fortress at the same time. In this way, the general captured the fortress and overthrew the dictator.

The technician/ lightbulb (less familiar target).

In a physics lab at a major university, a very expensive light bulb which would emit precisely controlled quantities of light was being used in some experiments. Suppose you are the research assistant responsible for the operation of the sensitive light bulb. One morning you come into the lab and find to your dismay that the light bulb no longer works. You realize that you had forgotten to turn it off the previous night. As a result the light bulb overheated, and the two wires in the filament inside the bulb have fused together. The surrounding glass bulb is completely sealed, so there is no way to open it. You know that the light bulb can be repaired if a brief, high-intensity ultrasound wave can be used to jar apart the fused parts. Furthermore, the lab has the necessary equipment to do the job. A high-intensity ultrasound wave, however, would also break the fragile glass surrounding the filament. Unfortunately, at lower intensities the ultrasound wave will not break the glass, but neither will it jar apart the fused parts. What type of procedure might you use to jar apart the fused parts with the ultrasound wave and at the same time avoid the necessity of buying a costly replacement bulb?

The firefighter (more familiar target).

An oil well in Saudi Arabia exploded and caught fire. The result was a blazing inferno that consumed an enormous quantity of oil each day and threatened to destroy the neighboring villages. After initial efforts to extinguish it failed, you are called in. You know that the fire can be put out if a huge amount of fire retardant foam can be dumped on the base of the well. There is enough foam available at the site to do the job, however there are no hoses large enough to put all the foam on the fire fast enough. The small hoses that are available cannot shoot the foam quickly enough to do any good. It looks like there will have to be a costly and potentially catastrophic delay before a serious attempt can be made to extinguish the fire. What type of procedure might you use to extinguish the fire with materials already available at the fire site and at the same time keep the fire from destroying the neighboring villages?

Convergence schema analogues from Anolli et al. (2001)

The lightbulb (target).

In a university lab a very expensive light bulb, which would emit precisely controlled quantities of light, was being used in some experiments. One morning the research assistant responsible for operating the sensitive light bulb came into the lab and found to her dismay

that the light bulb no longer worked. She realized that she had forgotten to turn it off the previous night. As a result the light bulb overheated, and the filament inside the bulb had broken into two parts. The surrounding glass bulb was completely sealed, so there was no way to open it. The light bulb could be repaired if a brief, high intensity laser ray could be used to fuse the two parts of the filament into one. Furthermore, the lab had the necessary equipment to do the job. However, a high-intensity laser ray would also break the fragile glass surrounding the filament. At lower intensity the laser ray would not break the glass, but neither would it fuse the filament. So it seemed that the light bulb could not be repaired. How could you solve this situation?

The artificial lake (source).

An engineer had to plan the construction of an artificial lake to produce electric energy. To feed the lake he thought to build a unique wide canal collecting water coming from a near valley. However, a mason pointed out that during the flood periods the stream of water flowing along the canal might be too strong and might damage the surrounding areas; by contrast, during the drought periods a unique stream of water might be insufficient to feed the lake. In order to avoid these mishaps, the mason suggested to build, instead of a unique wide canal, four small canals whose total flow was the same as the unique wide canal previously planned. These small canals were placed around the lake so that they conveyed water coming from four different valleys. In this way only small amounts of water could flow in each canal and thus during flood periods dangerous overflowing might not occur. At the same time, the lake was fed by water from various belts, so that also during drought periods it was sufficiently fed.

Convergence schema analogue from Antonietti and Gioletta (1995)

The artificial lake (source).

An engineer plans the construction of an artificial lake to produce electric energy. According to his first plan, a unique wide canal collects water coming from a valley and conveys it into the lake. However, the engineer realizes that during the flood periods the stream of water flowing along the canal may be too strong and may damage the surrounding areas. He also realizes that during the drought periods a unique stream of water may be insufficient to feed the lake. In order to avoid these mishaps, the engineer elaborates a second plan. According to this plan, the lake is fed by four small canals whose total flow is the same as the unique wide canal previously planned. These small canals are placed around the lake so that they convey water coming from four different valleys. In this way only small amounts of water can flow in each canal and thus during flood periods dangerous overflowing might not occur. At the same time, the lake is fed by water from various belts, so that also during drought periods it is sufficiently fed.

Antonietti et al. (2000): Original questionnaire descriptions of the five strategies (pp. 13-15)

Strategy 1.

I let my mind wander freely and try to produce as many ideas as possible, by avoiding to evaluate them at once. I consider each idea, even though it seems irrelevant, impossible to do or crazy. Only after having produced many ideas, I begin to analyse and to judge them and to choose the best ones.

Strategy 2.

I try to recall problems successfully solved in the past which are similar to the current problem. I look for previous situations which share some aspects, elements or features with the current problem so that I can transfer some ideas from the former ones to the latter one.

Strategy 3.

I try to go on systematically and to look for the sequence of steps or phases which are needed to reach the solution gradually. For instance, I try to decompose the whole problem into sub-problems, to identify intermediate goals, to plan, to schedule and to order hierarchically the operations to be carried out.

Strategy 4.

I try to visualise the problem, that is, to represent it in my mind through images. I try to see the situation with my mind's eye; I draw pictures, schemas, graphs, and so on. I actually imagine to be in that situation.

Strategy 5.

I try to combine different aspects of the problem. I try to associate, perhaps randomly, some elements of the problem so that I can reach any result, for instance by obtaining new patterns or interesting links which can suggest the solution.

Table A.1
List of databases searched

Databases	Databases
African-Wide	SABINET Online
Directory of Open Access Journals (DOAJ)	SAGE Journals Online
EBSCOHost (including ERIC and PBSC)	Science Direct
Google Scholar	Scopus
JSTOR	SpringerLink
Proquest	Taylor & Francis
PsycINFO (including PsycARTICLES and PsycTESTS)	Wiley Online Library

Appendix B

Table B.1

Pilot phase: Sample characteristics – continuous variables

Variable	n	Mean	Std. Dev.	Min.	Max.	Skewness	Kurtosis
Age	43	22.84	3.124	19	36	2.537	7.970
MP L	43	16.26	3.793	7	24	0.152	0.076
MP R	43	11.30	4.475	6	23	0.846	-0.048
MP I	43	16.86	4.074	9	23	-0.386	-0.912
MP DE	43	15.98	5.073	6	24	-0.102	-0.809

MP L = listening modal preference; MP R reading modal preference; MP I = iconic modal preference;
MP DE = direct experience modal preference

Table B.2

Pilot phase: Sample characteristics – categorical variables

Variable	Categories	n	%	Variable	Categories	n	%	
Gender	1 (male)	8	18.6	Reading fict. self	0 (no)	1	2.3	
	2 (female)	35	81.4		1 (yes)	42	97.7	
Faculty	1 (Humanities)	36	83.7	Reading non-f. self	0 (no)	2	4.7	
	2 (Science)	4	9.3		1 (yes)	41	95.3	
	3 (Commerce)	2	4.7		Reading fict. family	0 (no)	6	14.0
	4 (Engin. & BE)	1	2.3			1 (yes)	37	86.0
Year of study	3 (third year)	18	41.8	Reading non-f. family	0 (no)	4	9.3	
	4 (Honours)	12	27.9		1 (yes)	39	90.7	
	5 (Masters)	13	30.2		Electricity	0 (no)	1	2.3
Race	1 (Asian)	1	2.3	1 (yes)		42	97.7	
	2 (Black)	9	20.9	Hot water		0 (no)	2	4.7
	3 (Coloured)	1	2.3			1 (yes)	41	95.3
	4 (Indian)	8	18.6	Stove		0 (no)	1	2.3
	5 (White)	24	55.8		1 (yes)	42	97.7	
Home language	1 (English)	37	86.0	Fridge/freezer	0 (no)	1	2.3	
	2 (Afrikaans)	1	2.3		1 (yes)	42	97.7	
	3 (isiZulu)	2	4.7		Washing machine	0 (no)	2	4.7
	4 (isiXhosa)	1	2.3			1 (yes)	41	95.3
	5 (Sesotho)	1	2.3		Microwave oven	0 (no)	2	4.7
	10 (Xitsonga)	1	2.3			1 (yes)	41	95.3
Home language D.	1 (English)	37	86.0	PC	0 (no)	9	20.9	
	2 (other lang.)	6	14.0		1 (yes)	34	79.1	
No. spoken languages	1	26	60.5	Laptop	0 (no)	15	34.9	
	2	13	30.2		1 (yes)	28	65.1	
	3	2	4.7	TV	0 (no)	0	0.0	
	4	1	2.3		1 (yes)	43	100	
	5	1	2.3		VCR/ DVD player	0 (no)	4	9.3
High school language	1 (English)	36	83.7	1 (yes)		39	90.7	
	2 (other)	7	16.3	DSTV	0 (no)	11	25.6	
Prim. school language	1 (English)	35	81.4		1 (yes)	32	74.4	
	2 (other)	8	18.6	Hi-fi	0 (no)	3	7.0	
Type of schooling	1 (public)	18	41.9		1 (yes)	40	93.0	
	2 (private)	25	58.1	Telephone	0 (no)	3	7.0	
Rated English understanding	4	8	18.6		1 (yes)	40	93.0	
	5	35	81.4	SES	1 (low)	13	30.2	
Rated English reading	4	4	9.3		2 (ave.)	15	34.9	
	5	39	90.7		3 (high)	15	34.9	
Rated English writing	4	9	20.9					
	5	34	79.1					

Table B.3

Main phase: Sample characteristics – continuous variables

Variable	n	Mean	Std. Dev.	Min.	Max.	Skewness	Kurtosis
Age	655	19.08	2.142	18	39	4.951	32.645
MP L	658	15.76	4.027	0	24	-0.380	0.711
MP R	658	13.05	4.960	0	24	0.208	-0.726
MP I	658	16.31	4.676	0	24	-0.481	-0.112
MP DE	658	14.92	4.615	0	24	-0.071	-0.290

MP L = listening modal preference; MP R reading modal preference; MP I = iconic modal preference;
MP DE = direct experience modal preference

Table B.4

Main phase: Sample characteristics – categorical variables

Variable	Categories	n	%	Variable	Categories	n	%	
Gender	1 (male)	171	26.0	Rated	3	18	2.7	
	2 (female)	487	74.0		English	4	188	28.6
Faculty	1 (Humanities)	452	68.7	underst.	5	451	68.5	
	2 (Science)	121	18.4		missing	1	0.2	
	3 (Commerce)	55	8.4		Rated	3	13	2.0
	4 (other)	24	3.6		English	4	173	26.3
	missing	6	0.9		reading	5	471	71.5
Year of study	1 (first year)	606	92.1	Rated	missing	1	0.2	
	2 (undergrad.)	52	7.9		3	29	4.4	
Race	1 (Asian)	6	0.9	English	4	274	41.6	
	2 (Black)	305	46.4	writing	5	352	53.5	
	3 (Coloured)	50	7.6	missing	3	0.5		
	4 (Indian)	67	10.2	Reading fict.	0 (no)	158	24.0	
	5 (White)	229	34.8	self	1 (yes)	500	76.0	
	6 (other)	1	0.2	Reading	0 (no)	209	31.8	
Home language	1 (English)	378	57.4	non-f. self	1 (yes)	449	68.2	
	2 (Afrikaans)	21	3.2	Reading fict.	0 (no)	229	34.8	
	3 (isiZulu)	83	12.6	family	1 (yes)	429	68.2	
	4 (isiXhosa)	18	2.7	Reading	0 (no)	208	31.6	
	5 (Sesotho)	36	5.5	non-f. family	1 (yes)	450	68.4	
	6 (Sepedi)	35	5.3	Electricity	0 (no)	12	1.8	
	7 (Setswana)	36	5.5	1 (yes)	646	98.2		
	8 (Siswati)	11	1.7	Hot water	0 (no)	98	14.9	
	9 (Tshivenda)	10	1.5	1 (yes)	560	85.1		
	10 (Xitsonga)	9	1.4	Stove	0 (no)	39	5.9	
	11 (isiNdebele)	1	0.2	1 (yes)	619	94.1		
	14 (Portuguese)	3	0.5	Fridge/	0 (no)	24	3.6	
	17 (Shona)	5	0.8	freezer	1 (yes)	634	96.4	
	18 (French)	2	0.3	Washing	0 (no)	136	20.7	
	19 (Russian)	1	0.2	machine	1 (yes)	522	79.3	
	22 (German)	3	0.5	Microwave	0 (no)	88	13.4	
	23 (Mandarin)	2	0.3	oven	1 (yes)	570	86.6	
	24 (Bemba)	1	0.2	PC	0 (no)	254	38.6	
	26 (Turkish)	1	0.2	1 (yes)	404	61.4		
	28 (Swahili)	1	0.2	Laptop	0 (no)	330	50.2	
	missing	1	0.2	1 (yes)	328	49.8		
	Home language D.	1 (English)	378	57.4	TV	0 (no)	26	4.0
		2 (other)	279	42.4	1 (yes)	632	96.0	
missing		1	0.2	0 (no)	259	39.4		

No. spoken languages	1	274	41.6	VCR/ DVD player	1 (yes)	399	60.6
	2	290	44.1		DSTV	0 (no)	187	28.4
	3	64	9.7	Hi-fi	1 (yes)	471	71.6
	4	19	2.9		0 (no)	180	27.4
	5	9	1.4	Telephone	1 (yes)	478	72.6
	6	1	0.2		0 (no)	215	32.7
	8	1	0.2	SES	1 (yes)	443	67.3
	High school language	1 (English)	477		72.5	1 (low)	226	34.3
2 (other)		177	26.9		2 (ave.)	209	31.8
missing		4	0.6		3 (high)	222	33.7
Prim. school language	1 (English)	481	73.1	missing	1	0.2	
	2 (other)	174	26.4				
	missing	3	0.5				
Type of schooling	1 (public)	343	52.1				
	2 (private)	292	44.4				
	missing	23	3.5				

Appendix C



Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON MEDICAL)
H120406 Israel

CLEARANCE CERTIFICATE

PROTOCOL NUMBER H120406

PROJECT TITLE

The relationship between analogical problem solving and analogical reasoning

INVESTIGATOR(S)

Ms N Israel

SCHOOL/DEPARTMENT

Psychology

DATE CONSIDERED

20 April 2012

DECISION OF THE COMMITTEE

Approved Unconditionally

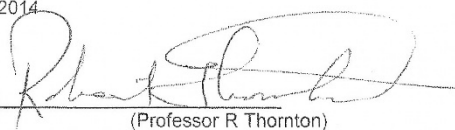
EXPIRY DATE

30 April 2014

DATE

23 April 2012


CHAIRPERSON


(Professor R Thornton)

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10005, 10th Floor, Senate House, University.

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**


Signature

11/05/12
Date

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

Appendix D



**SCHOOL OF HUMAN & COMMUNITY DEVELOPMENT
FACULTY OF HUMANITIES
UNIVERSITY OF THE WITWATERSRAND**

Private Bag 3, WITS, 2050
Tel: (011) 717 4500 Fax: (011) 717 4559



To whom it may concern,

My name is Nicky Israel and I am carrying out research for the purpose of obtaining a Doctorate of Philosophy in Psychology at the University of the Witwatersrand. The aim of my research is to explore the way in which people solve cognitive problems. These problems do not have only one solution, and my interest is in looking at how a person's reasoning ability may relate to the way in which they approach the problem and the kind/s of solution/s that they may propose. I would like to request your permission to access your students in order to invite them to participate in a pilot for my study.

Participation in the piloting study will involve completing a number of questionnaires related to cognitive tasks and problem solving. Students will be able to complete these questionnaires at home in their own time. They will be asked to complete two sets of questionnaires – the first should take approximately an hour and the second no more than twenty to thirty minutes.

Participation in this piloting is completely voluntary and choosing to participate in the study or not will have no direct impact on students' marks or any other aspects of their academic life. They will not be asked to provide any information that could directly identify them in the questionnaires and, as such, their responses will remain anonymous.

There are no foreseeable risks or harm to participation however there are two direct benefits for each participant:

- a) Every participant who completes the questionnaires will receive individual feedback related to their preferred method for learning or receiving information (modal preference). This will be carried out in a way that allows anonymity to be preserved.
- b) Every participant who completes the questionnaires will also be entered into a draw to potentially win one of several prizes. This will be carried out in a way that allows anonymity to be preserved.

The prizes in the draw are as follows:

- **First prize:** *a portable computing device (laptop/netbook)**
- **Second prize:** *an e-book reader (Kindle)**
- **Third prizes:** *memory sticks/flash drives – three to be awarded to three different people**

**[exact model and details to be finalised closer to the time – details to be inserted]*

Students will be reminded that participating in the study allows them to be entered into the draw, but it does not guarantee that they will definitely win one of the prizes.

If students choose to participate in the study, their questionnaires will only be accessed by myself, my supervisor and potentially a research assistant who has signed a confidentiality agreement; these are stored in a safe place and destroyed once the study is complete, although the data from them will be kept in summarized form.

If students choose to complete the questionnaires, they will be asked to return these within a specific timeframe to a sealed box and returning the completed questionnaires will be taken as informed consent to participate in the study. Analysis of the data will be of the group as a whole and other than the modal preference feedback, it will not be possible to give participants any other individual feedback from the study. They will, however, be able to access a summary of the more general results of the study once the research is complete.

If you have any questions or would like any further information, please feel free to contact me (011-717-4557; Nicky.Israel@wits.ac.za). You can also email my supervisor, Prof Kate Cockcroft (Kate.Cockcroft@wits.ac.za).

Thank you for considering allowing me access to your students to request participation in my research,
Yours sincerely,
Nicky Israel



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FACULTY OF HUMANITIES
UNIVERSITY OF THE WITWATERSRAND**

Private Bag 3, WITS, 2050
Tel: (011) 717 4500 Fax: (011) 717 4559



Dear potential participant,

My name is Nicky Israel and I am carrying out research for the purpose of obtaining a Doctorate of Philosophy in Psychology at the University of the Witwatersrand. The aim of my research is to explore the way in which people solve cognitive problems. These problems do not have only one solution, and my interest is in looking at how a person's reasoning ability may relate to the way in which they approach the problem and the kind/s of solution/s that they may propose. I would like to invite you to please consider taking part in the pilot for my study.

Participation in this piloting process will involve completing a number of questionnaires related to cognitive tasks and problem solving in two stages. The first stage will involve completing a set of questionnaires at home in your own time that should take approximately an hour to complete. You will be asked to please complete this questionnaire set in one sitting (i.e. at one time) and to time yourself to give an approximate estimate of how long it takes you. It is very important that you complete this questionnaire set on your own and do not ask for any assistance from anyone else.

Once you have completed this questionnaire set, you will be asked to return it and to collect feedback for one aspect of your responses approximately a week to two weeks later. With this feedback, you will be provided with a short 'piloting questionnaire' that should take no more than about fifteen to twenty minutes to complete. This questionnaire will ask you about your experiences of completing the first questionnaire set and will request any feedback or advice you have about improving the way the information has been collected. You will also be provided with a second blank copy of the questionnaire set for reference purposes only. When you have completed the second questionnaire, you will be asked to return it and the blank reference questionnaire set.

Participation in this pilot study is completely voluntary and choosing to participate in the study or not will have no direct impact on your marks or any other aspect of your academic life. You will not be asked to provide any information that could directly identify you in the questionnaires and, as such, your responses will remain anonymous.

There are no foreseeable risks or harm to participation however there are two direct benefits for each participant:

- a) Every participant who completes the questionnaires will receive individual feedback related to their preferred method for learning or receiving information (modal preference). In order to provide feedback while maintaining your anonymity, you have been provided with a unique four digit code at the top of this page and every other page in your questionnaire pack. When the results are analysed, feedback for your modal preference will be compiled into a report and sealed into an envelope with your unique four digit code on the front. This envelope will be left in the main office in the Department of Psychology (U211, second floor, Umthombo building) and can be collected between four to six weeks after you have returned your questionnaire pack for the study (please see below). Please detach this sheet and keep it safe in order to remember your four-digit code. The 'piloting questionnaire' and reference set will be provided with this feedback.
- b) Every participant who completes the questionnaires will also be entered into a draw to potentially win one of several prizes. This entry will be done using the unique four-digit code at the top of this and every other page in your questionnaire pack in order to preserve your anonymity. After this information sheet, you will find a single page that requests you to please fill in your name and contact details (phone number and email) and that also has your unique four-digit code at the top. As soon as you have completed this page, please detach it and place it in the separate box/ envelope provided.

Once the study is complete, all the four-digit codes will be collated and the winners drawn at random. A different person who is not connected to the study or data in any way will then match the code to the contact details sheet (which will be sealed separately in the box/envelope until then) and contact you to let you know that you have won one of the prizes and where to collect it. In this way, the researcher will have no access to your contact details or identity, and the person who knows who you are and lets you know about the prize will have no access to your answers – this will preserve your anonymity.

If you are one of the winners, in order to collect your prize **you will need to produce this information sheet with your unique code at the top**. Please detach this information sheet and keep it safe. No prize will be awarded if the person cannot produce this original information sheet with the correct four-digit code.

The prizes in the draw are as follows:

- **First prize:** *a portable computing device (laptop/netbook)**
- **Second prize:** *an e-book reader (Kindle)**
- **Third prizes:** *memory sticks/flash drives – three to be awarded to three different people**

**[exact model and details to be finalised closer to the time – details to be inserted]*

Please keep in mind that participating in the study allows you to be entered into the draw, but it does not guarantee that you will definitely win one of these prizes. Only those people who win prizes will be contacted. If the original winner is unable to collect the prize for whatever reason (for example, by losing this page) then an alternate winner will be drawn for that prize.

If you choose to participate in the study, your questionnaires will only be seen and coded by myself as the researcher, my supervisor or possibly a research assistant who will sign a confidentiality agreement. These questionnaires will be stored in a safe place and destroyed once the study is complete, although the data from them will be kept in summarized form. When answering the questions, please keep in mind that it is not important whether you come up with a correct or incorrect answer, and many of the questionnaires do not have any correct answers in any case. It is, however, vital that the questionnaires reflect only your answers and that you do not ask for help from anyone else.

If you choose to complete the questionnaires, you will be asked to return these within a specific timeframe to a sealed box placed either at the front of your lecture venue or in the Psychology main office (U211). **Returning the completed questionnaires will be taken as informed consent to participate in the study**. Analysis of the data will be of the group as a whole and other than the learning style preferences, it will not be possible to give you any other individual feedback from the study. You will, however, be able to access a summary of the more general results of the study once the research is complete. This summary will be posted on the noticeboard outside U306C on the third floor in the Umthombo building, and you can also obtain more information by contacting the researcher (please see contact details below).

If you have any questions or would like any further information, please feel free to contact me (011-717-4557; Nicky.Israel@wits.ac.za). You can also email my supervisor, Prof Kate Cockcroft (Kate.Cockcroft@wits.ac.za).

Thank you for considering participating in this research,
Yours sincerely,
Nicky Israel



**SCHOOL OF HUMAN & COMMUNITY DEVELOPMENT
FACULTY OF HUMANITIES
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Private Bag 3, WITS, 2050
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To whom it may concern,

My name is Nicky Israel and I am carrying out research for the purpose of obtaining a Doctorate of Philosophy in Psychology at the University of the Witwatersrand. The aim of my research is to explore the way in which people solve cognitive problems. These problems do not have only one solution, and my interest is in looking at how a person's reasoning ability may relate to the way in which they approach the problem and the kind/s of solution/s that they may propose. I would like to request your permission to access your students in order to invite them to participate in my study.

Participation in the study will involve completing a number of questionnaires related to cognitive tasks and problem solving. One of the questionnaires must be completed in person on campus – this will take approximately an hour in a session organized at a convenient and non-disruptive time. The rest of the questionnaires will take approximately another hour to complete and can be completed at the same time as the other questionnaire or can be taken home and completed in the participant's own time.

Participation in this study is completely voluntary and choosing to participate in the study or not will have no direct impact on students' marks or any other aspects of their academic life. They will not be asked to provide any information that could directly identify them in the questionnaires and, as such, their responses will remain anonymous.

There are no foreseeable risks or harm to participation however there are two direct benefits for each participant:

- a) Every participant who completes the questionnaires will receive individual feedback related to their preferred method for learning or receiving information (modal preference). This will be carried out in a way that allows anonymity to be preserved.
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**[exact model and details to be finalised closer to the time – details to be inserted]*

Students will be reminded that participating in the study allows them to be entered into the draw, but it does not guarantee that they will definitely win one of the prizes.

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Yours sincerely,
Nicky Israel



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Dear potential participant,

My name is Nicky Israel and I am carrying out research for the purpose of obtaining a Doctorate of Philosophy in Psychology at the University of the Witwatersrand. The aim of my research is to explore the way in which people solve cognitive problems. These problems do not have only one solution, and my interest is in looking at how a person's reasoning ability may relate to the way in which they approach the problem and the kind/s of solution/s that they may propose. I would like to invite you to please consider taking part in my study.

Participation in this study will involve completing a number of questionnaires related to cognitive tasks and problem solving. One of the questionnaires must be completed in person on campus – this will take approximately an hour. Dates, times and venues when group sessions for completing these will occur will be provided (you will only need to attend one of these sessions) or a suitable time can be organized on request. The rest of the questionnaires will take approximately another hour to complete and can be completed at the same time as the other questionnaire or can be taken home and completed in your own time.

Participation in this study is completely voluntary and choosing to participate in the study or not will have no direct impact on your marks or any other aspect of your academic life. You will not be asked to provide any information that could directly identify you in the questionnaires and, as such, your responses will remain anonymous.

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- b) Every participant who completes the questionnaires will also be entered into a draw to potentially win one of several prizes. This entry will be done using the unique four-digit code at the top of this and every other page in your questionnaire pack in order to preserve your anonymity. After this information sheet, you will find a single page that requests you to please fill in your name and contact details (phone number and email) and that also has your unique four-digit code at the top. As soon as you have completed this page, please detach it and place it in the separate box/ envelope provided.

Once the study is complete, all the four-digit codes will be collated and the winners drawn at random. A different person who is not connected to the study or data in any way will then match the code to the contact details sheet (which will be sealed separately in the box/ envelope until then) and contact you to let you know that you have won one of the prizes and where to collect it. In this way, the researcher will have no access to your contact details or identity, and the person who knows who you are and lets you know about the prize will have no access to your answers – this will preserve your anonymity.

If you are one of the winners, in order to collect your prize **you will need to produce this information sheet with your unique code at the top**. Please detach this information sheet and keep it safe. No prize will be awarded if the person cannot produce this original information sheet with the correct four-digit code.

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- **Third prizes:** *memory sticks/flash drives – three to be awarded to three different people**

**[exact models and details to be finalized at the end of the study]*

Please keep in mind that participating in the study allows you to be entered into the draw, but it does not guarantee that you will definitely win one of these prizes. Only those people who win prizes will be contacted. If the original winner is unable to collect the prize for whatever reason (for example, by losing this page) then an alternate winner will be drawn for that prize.

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If you choose to complete the questionnaires, you will be asked to return these within a specific timeframe to a sealed box placed either at the front of your lecture venue or in the Psychology main office (U211). **Returning the completed questionnaires will be taken as informed consent to participate in the study.** Analysis of the data will be of the group as a whole and other than the learning style preferences, it will not be possible to give you any other individual feedback from the study. You will, however, be able to access a summary of the more general results of the study once the research is complete. This summary will be posted on the noticeboard outside U306C on the third floor in the Umthombo building, and you can also obtain more information by contacting the researcher (please see contact details below).

If you have any questions or would like any further information, please feel free to contact me (011-717-4557; Nicky.Israel@wits.ac.za). You can also email my supervisor, Prof Kate Cockcroft (Kate.Cockcroft@wits.ac.za).

Thank you for considering participating in this research,
Yours sincerely,
Nicky Israel

Appendix E

CONTACT DETAILS INFORMATION

As soon as you have completed this sheet, please detach it from the rest of the questionnaire and place it in the sealed box/ envelope provided. This will ensure that you remain anonymous but can be contacted if you should win a prize for the draw.

Name & Surname: _____

Cellphone Number/s: _____

Landline Number/s: _____

Email Address/es: _____

Thank you!

Modal Preference Feedback Sheet

Dear participant _____ (**insert participant code**) _____,

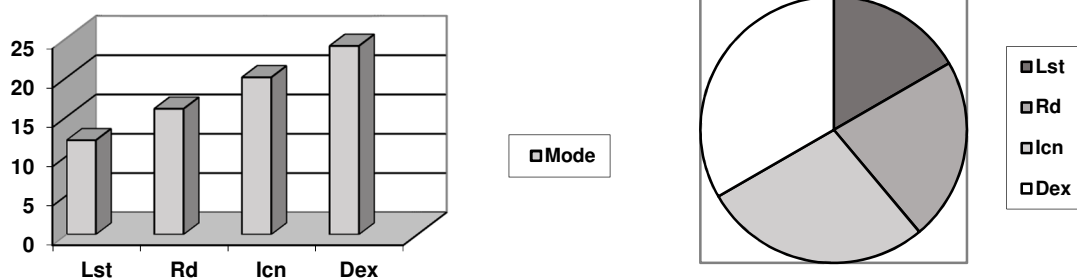
Thank you for taking the time to participate in the study.

Below you will find information and feedback about the way in which you prefer to learn information presented in class (i.e. your preferred method or mode of learning).

Before looking specifically at your profile, it is very important to remember the following:

- **Learning preferences tell you about how you like to do things; they do not indicate your ability to do those things!**
- **There is no right or wrong preferred way to learn.** All people are different. This is not about finding a 'correct' answer, rather it is about helping you to recognize what your preferences are; specifically how you enjoy receiving information (mode) you need to learn.
- **Your preferences are not fixed** and can change over time or in different environments.
- **You can have more than one preference!** In fact, many people have more than one preferred way of learning that they have developed over time.
- No mode preference is more or less effective than the others in general. You may find, however, that based on the particular kind of teaching you are receiving and the context, certain preferences can help you to learn or make it more difficult to learn in specific classes or when working with particular teachers or lecturers.
- By understanding your different preferences, it may make it easier for you to understand why you find parts of your studies easier and others harder. It may also help you to develop some effective ways of working with the material you cover to make sure it is in a form that you enjoy working with, which may improve your performance.
- If you would like to gain further understanding of your learning preferences, you may find it useful to consult the following:
 - **For a more detailed assessment of your preferred learning style/s:**
 - MEMLETICS Learning Styles Questionnaire (online): <http://www.learning-styles-online.com>
 - VARK: <http://www.vark-learn.com/english/index.asp>
 - **For a general overview of theories about learning styles:**
 - Wikipedia: <http://en.wikipedia.org/wiki/Learning-styles>
 - Pritchard, A. (2008). Ways of Learning: Learning theories and learning styles in the classroom (2nd Ed.). New York: Taylor & Francis.

Mode Preference



The graphs above reflect four types of preference for the way in which you are provided with material by your lecturer, tutor or instructor:

Preference	Code	Your preference for...
<i>Listening</i>	<i>(Lst)</i>	...hearing information; listening to lectures, tapes, speeches etc...
<i>Reading</i>	<i>(Rd)</i>	... reading; receiving information through written formats such as texts, textbooks, pamphlets etc...
<i>Iconic</i>	<i>(lcn)</i>	... viewing; watching movies or seeing slides, illustrations, pictures, graphs etc...
<i>Direct Experience</i>	<i>(DEx)</i>	... practical; performing; handling objects in laboratories or workshops or working with material on field trips or through practical exercises etc...

The higher the column in the first graph or the larger the slice in the second graph for that preference, the more important that particular preference is to you when you learn or are in the classroom.

- If you have a **high preference for learning by LISTENING**, you like music and sound and to receive information verbally or aurally (through your ears). You may find it useful to develop rhymes or mnemonics (letters representing principles) to remember your work, or you may find it useful to learn while humming a tune or song to help you remember. Repetition aloud or recording and listening back may be useful as well. You may be easily distracted in noisy environments, so try to find a quiet place to study.
- If you have a **high preference for learning by READING**, you like text and words and to receive information in written form. You may find it useful to use highlighters or colours to underline important points and also to write out verbal summaries you can re-read to learn. You may also find it useful to create lists or point-form summaries you can work through. You may find it difficult to listen effectively and write detailed notes at the same time, so perhaps record your lectures and transcribe (re-write) them later or use point form and write out your notes in more detail later on.
- If you have a **high preference for learning ICONICALLY**, you like pictures and graphs and to receive information visually (through your eyes). You may find it useful to create mind-maps or diagrams or visual summaries of important material, or to associate pictures with important concepts. You may also like to imagine scenarios or create stories to link concepts together and to use lots of colour to separate ideas.

You may find yourself easily distracted by movement or colour in the classroom, so try to study in a quiet static place away from windows.

- If you have a **high preference for learning by DIRECT EXPERIENCE**, you like movement and hand-on experience and to receive information kinaesthetically (through movement and your senses). You may find it useful to act out important ideas or study while doing something physical (for example, throwing a ball or tapping). You may also find it useful to imagine how things would feel or a sequence of what would happen when learning, or to use flashcards with key ideas on them that you can move around. You may become easily distracted if you have to sit still for too long, so try to find non-disruptive ways to move around or re-focus while in class or studying (for example, breathing exercises, moving fingers and toes etc...).

- Very few people prefer to receive information in only one way, so spend some time thinking about how you can best combine your preferred methods of receiving information. For example, if you have preferences for learning iconically and through reading, perhaps write out your notes and then summarise them in a mind-map; if you like learning through direct experience and by listening, perhaps play some music and tap out a rhythm while you learn etcetera...

- Keep in mind that in most classes, you receive information through reading and listening. Even if these are not your preferred ways of learning, trying some of the examples of how to learn given for these may help you to learn more effectively in that class and understand how to change the information into a form that you prefer learning.

- Remember, you can have more than one preference and preferences do change over time

=====

If anything discussed in this report or in the study more generally concerns you, you may find it useful to contact the Counselling and Career Development Unit (CCDU) at the University of the Witwatersrand on 011-717-9140 or the Emthonjeni Centre at the University of the Witwatersrand on 011-717-4513.

Thank you again for taking the time to participate in the study.

Procedure for obtaining credit for Psychology courses due to participation



SCHOOL OF HUMAN & COMMUNITY DEVELOPMENT FACULTY OF HUMANITIES UNIVERSITY OF THE WITWATERSRAND

Private Bag 3, WITS, 2050
Tel: (011) 717 4500 Fax: (011) 717 4559



Dear potential **[insert relevant year-level]** Psychology participant,

As you may be aware, in addition to the benefits outlined in the informed consent sheet attached to this pack, as a Psychology **[insert year-level]** student you are also eligible to obtain credit towards your final coursemark for participating in research projects. This project is one of the projects for which you are able to obtain credit for participating however it is not the only project which will allow you to do so and you are reminded that you will be given many opportunities to obtain this credit if you wish. However, should you choose to participate in this study, you will be able to obtain **[insert relevant percentage – maximum = 2-3%]** credit towards your final **[insert relevant year-level]** Psychology mark.

In order to credit you with participating in this research, it will be necessary for you to obtain a proof of participation slip. In addition, I, as the researcher, am required to obtain a list of participants for cross-verification purposes. In order to allow you to remain anonymous but still meet these requirements, you will be asked to provide the course code/s in Psychology for which you are registered and your student number in the space below but not your name.

You will notice that unlike the other pages in this pack, this page and the next page do not contain your participant number. As soon as you hand in the completed pack as per the procedure in the informed consent sheet, this page will be separated from the rest of the pack. Once this is done, there will be no way to link your student number to any of the data you have provided and your responses will therefore be completely anonymous.

As the researcher I will then compile a list of participants by student number only. Thus I will have no access to your name or individual identity. This list will then be given to the relevant course coordinator/s and administrator/s to allow them to credit you. The course coordinator/s and administrator/s will thus be aware that you participated in research but not what your responses were – they will have no access to any of your data.

In addition, I will print individual participation slips by student number only and these will be left in the main office in the Department of Psychology (U211, second floor, Umthombo building) and can be collected between four to six weeks after you have returned your questionnaire pack for the study.

If you agree to provide your student number and the course code/s for Psychology for which you are currently registered below strictly for the purposes of obtaining credit as per the conditions outlined above, please fill in the slip on the next page. Please detach and keep this sheet.

Student Number and Psychology Codes
(for Obtaining Course Credit Only)

Student Number:

--	--	--	--	--	--	--	--	--

Course codes:

THANK YOU!

PROOF OF PARTICIPATION SLIP

This slip hereby serves to confirm that student:

Student Number:

--	--	--	--	--	--	--	--	--

***participated in a PhD-level study conducted by a student in
the Department of Psychology at the University of the
Witwatersrand and is thus eligible to receive course credit
for this participation.***

Signed: _____

Date: _____

Appendix F

Demographic Questionnaire

Please complete the following. Please note that all questions are for descriptive and analytic purposes only and are in no way meant to be offensive.

1. What is your age? _____ years

2. Are you male or female (please put a cross next to whichever is appropriate)?

Male		Female	
------	--	--------	--

3. To which group do you belong (please put a cross underneath whichever is appropriate)?

Asian	Black	Coloured	Indian	White	Other (please specify):

4. Which faculty are you registered in?

Humanities	Science	Commerce	Engineering & Built Env't.	Health	Other (please specify)

5. In which year of study at university are you?

First	Second	Third	Fourth	Honours	Masters	PhD	Other (please specify):

6. Which language/s do you speak **fluently**? _____

7. Which language do you speak **most often** at home? _____

8. Which language/s did your teachers speak when **teaching you in high school**?

9. Which language/s did your teachers speak when **teaching you in primary school**?

10. Which type of school did you attend? (please put a cross underneath whichever are appropriate)

Urban	Rural		Government	Private		GED	IEB	Other (please specify):

11. Please rate your ability for each of the following (please put a cross underneath whichever is appropriate):

	Excellent	Good	Adequate	Poor	Very poor
1. Understanding English					
2. Reading in English					
3. Writing in English					

4. Your performance at university (if you have not yet completed any assignments, please leave this blank)					
--	--	--	--	--	--

12. Please give your **parent/s' or guardian's occupations**. Fill in whichever is applicable to you:

Father (e.g. teacher, driver; unemployed): _____

Mother (e.g. lawyer, domestic worker; housewife): _____

Guardian (e.g. doctor, self-employed): _____

13. Please give the highest **level of education** completed **by your parents**. Fill in whichever is applicable to you:

Father (e.g. Std 5/ Grade 7, BA): _____

Mother (e.g. Std 7/ Grade 9, LLB): _____

Guardian (e.g. Matric, BSc): _____

14. Please indicate which of the following you had in the house where you grew up (please cross whichever is appropriate):

Electricity	Hot water/ geyser	Electric stove	Fridge/ freezer	Washing machine	Microwave oven

Personal computer	Laptop	TV set	VCR	DSTV/ MNET subscription	Hi-fi/ music centre	Landline telephone

Books (fiction) that you read	Books (non-fiction) that you read	Books (fiction) that your parents/ family read	Books (non-fiction) that your parents/ family read

15. Please read the following questions carefully and rank the responses as 1, 2, 3 or 4 according to how well they describe your preferred way of learning. **1 is the most preferred rank, then 2, then 3 and 4 is the least preferred rank.**

For example:

EG 1. Rank the following food items in the order that you most prefer them:

RANK		
2	Pizza	(second)
4	Fresh fruit and vegetables	(least preferred)
1	Chocolate and ice-cream	(most preferred)
3	Steak	(third)

15a) Rank the following in terms of their general value to you as ways to learn.

RANK	
	Listening to others talk about a subject
	Reading what others have written about it
	Seeing pictures, graphs, movies etc...
	Handling or working with something tangible

15b) Classes typically involve the following kinds of teaching activities. Rank them in the order in which you generally prefer them as ways to learn.

RANK	
	Lectures, audio-tapes and question-answer sessions
	Textbook assignments and other readings
	Movies, slides, graphics, charts etc...
	Experiments or projects in the laboratory

15c) How do the following appeal to you as ways to find out about new occupations or types of work?

RANK	
	Having someone in the field tell me about it
	Read a recent study explaining it
	Watch a classroom demonstration of the work
	Trying to do the work itself

15d) Rank the following in the order in which you would typically like to learn about the properties of a new plastic.

RANK	
	Hearing a lecture
	Reading a book or text
	Viewing a movie or slides
	Experimenting with a small sample

15e) Imagine you're taking an ecology course. Rank the ways you'd like to study the topic.

RANK	
	Hear speeches by qualified people
	Read reports and studies
	Watch movies, TV, films etc...
	Take field trips

15f) Rank the following class activities in the order in which they normally appeal to you.

RANK	
	The teacher lectures and answers questions
	I can read about the topic in a text or some outside reading
	Pictures, movies, graphs, displays etc... are used
	I can experiment with or actually use the material

Thank you!! ☺ Please turn over!

Analogical Problem Solving: Source/titled 'Reading Comprehension'

Please read the following passage carefully and answer the questions that follow:

A small country was ruled from a strong fortress by a dictator. The fortress was situated in the middle of the country, surrounded by farms and villages. A rebel general knew that if he attacked with his entire army at the same time he would be able to capture the fortress. However, the general also knew that the dictator had planted mines on each of the roads leading to the fortress. The mines were set so that small numbers of men could pass over them safely, since the dictator needed to move his own troops and workers to and from the fortress. However, any large force would detonate the mines. Not only would this blow up the road, but it would also destroy many neighboring villages. It therefore seemed impossible to capture the fortress.

The rebel general was in despair however he then remembered a story told to him by his grandmother about a fire in their village. A very large building had been on fire and to put it out, the villagers had needed to put a large amount of water on it at the same time but they had only had small buckets available. One of the villagers had then had a brilliant idea – he had had each villager fill one of the small buckets with water and wait in a circle surrounding the building. When everyone was ready, he gave a signal and each villager threw their water on the fire at the same time, extinguishing the fire.

After remembering the story, the general devised a simple plan. He divided his army into small groups and sent each group to a different road. When all was ready he gave the signal and each group marched down its road to the fortress so that the entire army arrived together at the fortress at the same time. In this way, the general captured the fortress and overthrew the dictator.

- 1) Why was the rebel general not able to send all his troops down one road at the same time to capture the fortress?**

- 2) How did the villagers solve their problem and put out the fire?**

- 3) How did the rebel general solve his problem and get his troops to the fortress?**

- 4) Why do you think that his grandmother's story led the general to the solution to his problem?**

Analogical Problem Solving: Target/ titled 'Creative Problem-Solving I'

Please read the following passage:

A major aquarium near Durban decided to create a large display containing a replica of a sunken ship and the surrounding seabed near to where it sank. A professional aquarium designer was assigned to the project. She placed a small replica of the ship in the centre of a large tank, with sand representing the seabed underneath. Then she added plants and fish of the sort that live near where the ship had sunk.

The display was virtually finished when the designer was confronted with a major problem she had failed to anticipate. In order to maintain the deep-water environment required by the fish and plants, the tank had to be kept quite dark, as the deep-water organisms were not adapted to light. However, if the tank was kept completely dark, people would not be able to see the small replica of the ship in the centre of the tank, which, after all, was the main point of the exhibit.

Putting a light inside the replica ship itself looked too artificial. The designer then considered shining a very powerful spotlight on the model of the vessel. However, if this spotlight was located inside the tank, it would raise the temperature of the water too high. The designer then put the spotlight outside the tank, but if it was located outside the tank, the bright beam seriously disrupted the feeding habits of some of the fish. The designer tried desperately to think of another solution to light the display...

What could be done to light the display?

Please write down as many ways to tackle this problem as possible, including those ways you think would not work as well as those that would.

If you think the way would not work, please briefly explain why.

When you have finished, please look at those ways you think would work and identify the one you feel would be best. Please label this as number 1. Please continue numbering each of these in the order you prefer them (so the next best as 2, the next as 3 etc...).

Analogical Problem Solving: Open-Ended Example 1/Titled: Creative Problem Solving II

Please read the following:

In summer, a small bird was on a long journey to join up with the rest of its flock. During the trip, it became very thirsty but could not find any open water to drink. Finally, it landed in a field and found a bottle half full of water. It put its beak into the bottle and stretched its neck but the water was too low in the bottle for it to reach. The bird was too weak to continue to fly without any water. The field was empty except for some grass, a few plants, loose pebbles and some flowers.

What could the bird do to reach the water and continue on its journey?

Please write down as many ways to tackle this problem as possible.

When you have finished, please look at each solution and identify the one you feel would be best. Please label this as number 1. Please continue numbering each of these in the order you prefer them (so the next best as 2, the next as 3 etc...).

Analogical Problem Solving: Open-Ended Example 2/Titled: Creative Problem Solving III

Please read the following:

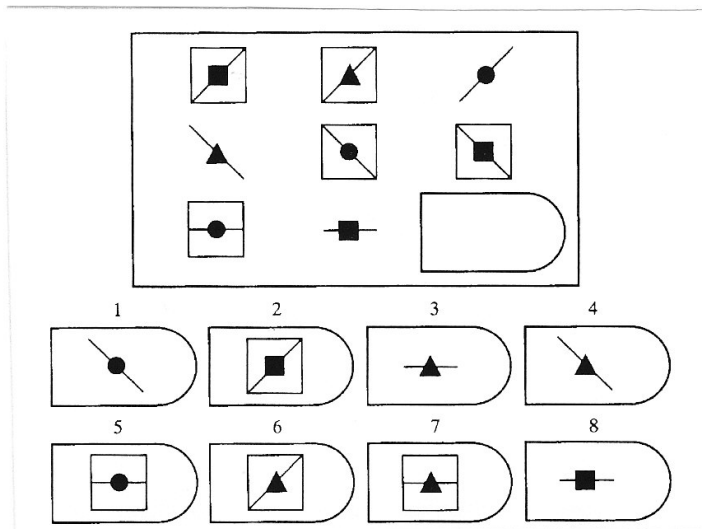
A group of boys were playing a game of table-tennis in a garage during their summer holidays. During the last match, one of the boys hit the ping-pong ball they were using very hard and it rolled across the garage and into a small but deep hole in the wall. The hole was curved and was too narrow and deep for the boys to reach the ball however unfortunately they did not have another ball to continue playing with. The boys searched their pockets and found they had some sweets, a pack of chewing gum, some loose change and their cellphones. Looking around the garage, they saw a broom, a rake, a hosepipe connected to a tap on the wall, a pair of garden gloves, a can of bug spray, some paint tins and a spade.

What could the boys do to retrieve the ball and continue their game?

Please write down as many ways to tackle this problem as possible.

When you have finished, please look at each solution and identify the one you feel would be best. Please label this as number 1. Please continue numbering each of these in the order you prefer them (so the next best as 2, the next as 3 etc...).

Raven's Advanced Progressive Matrices: Example Item



Taken from:

Vodegel Matzen, L.B., van der Molen, M.W. & Dudink, A.C.M. (1994). Error analysis of Raven Test Performance. *Personality and Individual Differences*, 16, 433-445.

Self-Developed Analogies Task

A four-term analogy consists of four words that relate to each other as follows: A is to B as C is to D. In other words, there is a relationship between A and B, and the same kind of relationship exists between C and D.

For example, one analogy would be “dog is to puppy as cat is to kitten”. A puppy is a baby dog, and similarly, a kitten is a baby cat, therefore there is the same relationship between puppy and dog as there is between cat and kitten. Other examples are “spring is to summer as autumn is to winter” and “scissors are to cut as pen is to write”.

The following exercise requires you to select the option you feel best completes the missing part of each of the analogies below. You will need to choose your answer from one of the six possibilities provided. Please choose **only one answer**. Please **write the letter of the option you choose clearly in the space provided**.

E.g. Water is to thirsty as food is to _____ **C** _____:

a) drink	b) hunger	c) hungry
d) eat	e) thirsty	f) famine

1. Happiness is to smile as sadness is to _____:

a) misery	b) cry	c) frown
d) depression	e) sadness	f) anger

2. Car is to petrol as lightbulb is to _____:

a) electricity	b) light	c) petrol
d) luminescence	e) glass	f) filament

3. Often is to frequently as seldom is to _____:

a) never	b) frequently	c) kingdom
d) repeatedly	e) sometimes	f) rarely

4. Boy is to child as man is to _____:

a) boy	b) guy	c) woman
d) adult	e) human	f) masculine

5. Walk is to run as talk is to _____:

a) converse	b) conversation	c) walk
d) dance	e) shout	f) screech

6. Light is to dark as peace is to _____:

a) destruction	b) war	c) calm
d) dove	e) light	f) confrontation

7. Apple is to peach as cabbage is to _____:

a) cauliflower	b) apple	c) banana
d) pear	e) beetroot	f) parsley

8. Tyre is to rubber as candle is to _____:

a) flame	b) light	c) wax
d) rubber	e) wick	f) flammable material

9. Musician is to entertain as lecturer is to _____:

a) award marks	b) entertain	c) professor
d) teach	e) lecture	f) office

10. Add is to increase as subtract is to _____:

a) minus	b) add	c) exclude
d) divide	e) reduce	f) multiply

11. Grass is to field as seaweed is to _____:

a) ocean	b) water	c) beach
d) sushi	e) grass	f) deep sea

12. Leopard is to spot as zebra is to _____:

a) spot	b) stripe	c) horse
d) dot	e) hide	f) black-and-white

13. Second is to minute as month is to _____:

a) clock	b) time	c) second
d) year	e) day	f) decade

14. Problem is to solution as disease is to _____:

a) treatment	b) medicine	c) solution
d) fever	e) dirty	f) cure

15. Foot is to toe as hand is to _____:

a) finger	b) digit	c) grasp
d) knuckle	e) glove	f) foot

16. Boil is to steam as freeze is to _____:

a) cold	b) boil	c) burn
d) ice-cream	e) cubes	f) ice

17. Apple is to fruit as potato is to _____:

a) root	b) fruit	c) vegetable
d) French fries	e) onion	f) produce

18. Bracelet is to wrist as ring is to _____:

a) fourth finger	b) hand	c) marriage
d) necklace	e) finger	f) wrist

19. Media is to news as university is to _____:

a) degree	b) education	c) lessons
d) lecturers	e) high school	f) news

20. Ambivalent is to unclear as valuable is to _____:

a) treasure	b) valuable	c) worthless
d) precious	e) desired	f) costly

21. Lake is to ocean as hill is to _____:

a) foothill	b) hill	c) mountain
d) peak	e) valley	f) snow

22. Poem is to verse as essay is to _____:

a) format	b) spell-check	c) word limit
d) essay	e) sentences	f) paragraph

23. Rain is to raindrops as sand is to _____:

a) pieces	b) grains	c) soil
d) rubs	e) beach	f) sand

24. Bicycle is to handlebars as car is to _____:

a) steering wheel	b) wheels	c) petrol
d) power-steering	e) bicycle	f) engine

25. Crate is to carpet as treat is to _____:

a) partner	b) patter	c) paste
d) carpet	e) plate	f) trait

26. Plate is to eat as cup is to _____:

a) sip	b) plate	c) coffee
d) taste	e) drink	f) soup

27. Chicken is to egg as plant is to _____:

a) seed	b) fruit	c) egg
d) weed	e) shoots	f) bread

28. Knife is to cutlery as chair is to _____:

a) fixtures	b) seating	c) table
d) bed	e) furniture	f) knife

29. Tricycle is to bicycle as trio is to _____:

a) duet	b) two wheels	c) pair
d) value	e) tricycle	f) motorcycle

30. Democracy is to freedom as dictatorship is to _____:

a) government	b) oppression	c) leadership
d) stress	e) freedom	f) torture

31. Fourth is to fifth as April is to _____:

a) 5 th April	b) month	c) spring
d) May	e) fourth	f) Easter

32. Noon is to eve as 12:21 is to _____:

a) 08:08	b) 19:00	c) 10:00
d) 12:02	e) 17:00	f) 10:01

Adapted Problem Solving Preferences Questionnaire

The following questions relate to the ways in which you approach solving problems in academic or practical contexts, in other words, problems that are not social or emotional in nature. There are no right or wrong answers.

Please read the items carefully. Each item is a possible way that you might approach solving a problem. For each, please indicate how often you use this approach (**A = 'Always'; O = 'Often'; ST = 'Sometimes'; S = 'Seldom'; and N = 'Never'**). In each case, please indicate your answer by placing a cross over or circling your choice.

I 'brainstorm' to come up with as many solutions as possible	A	O	ST	S	N
I try to recall problems that I have solved in the past that were similar to the current problem	A	O	ST	S	N
I try to identify sequences, steps or phases that could be used to reach the solution gradually	A	O	ST	S	N
I try to represent the problem in a different way, for example, by drawing pictures or graphs or using mind-maps etc...	A	O	ST	S	N
I try to associate different elements of the problem to look for interesting or unusual patterns or links	A	O	ST	S	N
I try to think creatively and freely and produce as many ideas as possible, even if they seem crazy or irrelevant	A	O	ST	S	N
I look for previous situations which share some aspects, elements or features of the current problem so that I can transfer ideas	A	O	ST	S	N
I try to break down the problem into smaller sub-problems and solve each one to reach the final solution	A	O	ST	S	N
I try to imagine what the best way to solve the problem would be	A	O	ST	S	N
I try to combine different aspects of the problem to come up with a creative solution	A	O	ST	S	N
I do not evaluate my ideas initially but wait until I have produced many ideas and only then do I begin to analyze and judge them and choose the best ones	A	O	ST	S	N
I try to think of the principles I used to solve previous problems that were similar	A	O	ST	S	N
I try to systematically plan and order the steps I need to take to solve the problem	A	O	ST	S	N
I try to re-structure or re-formulate the problem into a format that is easiest for me to work with	A	O	ST	S	N
I try to create new combinations from my existing knowledge about the problem	A	O	ST	S	N
I try to do something else until a solution 'pops' into my mind	A	O	ST	S	N
I try to rule out aspects of the problem that do not seem strictly relevant	A	O	ST	S	N
I think of an idea and then test it out to see if it works	A	O	ST	S	N
I try to think of what someone else would do in the same situation	A	O	ST	S	N
I try to get help from others	A	O	ST	S	N

Pilot Questionnaire

Dear participant,

Firstly thank you for agreeing to take part in the pilot study for this research.

As you may be aware, a pilot study is when a researcher carries out their intended research procedures with a small group of participants in order to assess whether the way they intend to gather their data is appropriate and effective. In this case, I am specifically exploring whether the instruments you have completed are effective and appropriate in the South African context and whether they accurately measure the ideas I am trying to assess.

It would be extremely helpful if you could please answer the following questions as honestly and completely as possible. Please feel free to make any additional comments you feel would be useful as well – space has been left at the end for this.

1. How long did it take you to finish the entire questionnaire?

2. Did you obtain any help when completing any part of the questionnaire? **YES / NO**
If YES, please explain for which question/s and why.

3. Did you find the instructions for each section of the questionnaire easy to follow?

The demographic questionnaire, including ranking your preferred way of learning	YES	NO
The reading comprehension exercise	YES	NO
The analogies	YES	NO
The creative problem solving exercises	YES	NO
The questionnaire about your approach to solving problems	YES	NO

If you answered NO for any of the above, please explain. Any information about how to improve the instructions would be particularly appreciated.

P.T.O.

4. For each section, were there any questions/ items that concerned you in terms of:
- the nature of the question (too personal or difficult to answer)
 - the language of the question (difficult to understand; too formal; unclear etc...)
 - understandability
 - inappropriate for the South African context
 - just in general

The demographic questionnaire, including ranking your preferred way of learning	YES	NO
The reading comprehension exercise	YES	NO
The analogies	YES	NO
The creative problem solving exercises	YES	NO
The questionnaire about your approach to solving problems	YES	NO

If you answered YES for any of the above, please explain. Any information about the specific nature of the problem/s and how to improve the question/s would be particularly appreciated.

5. Do you think that other students would be willing to volunteer for this study?
YES / NO
 Please explain your answer briefly:

6. For the feedback regarding your preferred mode of learning, was the feedback sheet:

Easy to understand	YES	NO
Useful	YES	NO
Interesting	YES	NO

If you answered NO for any of the above, please explain. Any information about how to improve the feedback sheet would be particularly appreciated.

7. Are there any additional points you would like to make? Any additional information would be much appreciated.

Thank you!! 😊

Appendix G

Table G.1

Pilot phase: Time taken to complete the questionnaire pack

Time	n	%
30 min or less	2	6%
31 to 35 min	1	3%
36 to 40 min	6	18%
41 to 45 min	6	18%
46 to 50 min	4	12%
51 to 55 min	0	0%
56 to 60 min	5	15%
61 to 70 min	4	12%
71 to 80 min	2	6%
81 to 85 min	1	3%
85 to 90 min	1	3%
90 min or more	1	3%

Table G.2

Pilot phase: Concerns re individual measures

Measure	Yes	No
The demographic questionnaire and the modal preference questionnaire	3 (9%)	30 (91%)
The reading comprehension exercise (spontaneous transfer source)	1 (3%)	32 (97%)
The verbal analogical reasoning task	6 (18%)	27 (82%)
The creative problem solving exercises (spontaneous transfer target and the open source problems)	6 (18%)	27 (82%)
The self-reported heuristic strategy preference questionnaire	4 (12%)	29 (88%)

Table G.3

Pilot and main phase: Solution codes for the spontaneous/ directed transfer task (aquarium problem)

Code	Description
ANS1DLS	Stage 1 different less powerful light source (e.g. LED lights/candles/UV light/coloured lights/energy efficient bulbs/shadow lights/fairy lights/metal halide lamps/infrared)
ANS1DP	Stage 1 different position for lights (further away/ below/ above/on pole/behind/outside water)
ANS1RI	Stage 1 reduced intensity (dim lights)
ANS2TRC	Stage 2 torches/ independent lights/ miner's helmets (self-lighting)
ANS2ML	Stage 2 multiple (smaller) lights
ANS3CD	Stage 3 circular disposition
ANS4SS	Stage 4 simultaneous summation/ application
NADJT	Adjustable light intensity; alternating lighting/ rotating lighting
NADPT	Use fish/plants adapted to shallow water/ sunlight (genetic adaptation)
NADPTP	Create process of adaptation (e.g. light exposure, regular feeding)
NARTF	Use artificial fish/ plants (i.e. artificial stock)

NBARR	Barriers in the tank/ partitions/ glass dividers/shelter
NFLOR	Fluorescent/ neon/ glow in the dark/ luminescent animals and objects/ glow sticks
NGOGG	Night vision goggles/ UV goggles
NGOGGS	Camera system/ telescope/ night vision screen
NLCVR	Light covering/ light barrier/ hidden lights in sand
NLITK	Light inside tank despite conditions of problem – disregard effect
NLRGE	Larger replica
NPICT	Pictures/ models/ additional information/ alternate presentation
NPNTT	Tank painted dark
NPNTTL	Tank painted light
NPOST	Change replica location or positioning (corner, side); have tank large enough to walk through or swim in
NREFL	Reflective surfaces/ mirrors/ paint/ bright coloured paint
NREMV	Remove fish/ plants; have separate tanks
NROOM	Room kept dark
NROOML	Room lit well
NRSCH	Further research/ expert assistance/ develop a new type of light
NSENS	Controlled lighting/ sensor lights controlled by human presence
NSNRF	Skylight/ sunlight/ natural lighting/ sunroof/ window
NTINT	Tinted windows/ light resistant windows/ UV proof glass
NTMPC	Temperature control in the tank (e.g. cooling system/ thermostat/ adding cooler water/ heat extractor or cool room)
NVISH	Time-controlled lighting (time switch/timer); linked to visiting hours

Table G.4

Pilot and main phase: Solution codes for the open transfer task (thirsty bird problem)

Code	Description
XALTW	Find an alternate water source
XANGL	Tilt/ angle bottle (e.g. lift bottle on beak)
XBRKB	Break bottle
XCTCH	Pour water onto an object/ into a hole to act as a catchment area/ device
XDEWR	Wait for dew or rain
XDIPP	Put a blade of grass/ leaf/ flower in the water and pull it out, then drink a drop or two off the end and repeat
XEATS	Eat plants or insects; drink nectar as an alternate source of water
XHELP	Get help from other birds/ humans
XHOLE	Make a hole in the bottle
XHRZN	Place bottle horizontally; knock bottle sideways
XINCL	Create an incline/ fulcrum to tilt bottle at a different angle
XKOVR	Knock bottle over (drink from what spills on the ground)
XPEBB	Put pebbles/ other material in bottle to raise water level (displacement)
XREST	Rest to gain strength to carry on
XROLL	Roll the bottle over objects/ rough ground; shake bottle
XSHPB	Change shape of bottle (e.g. cut in half, squeeze bottom, break top)
XSTPR	Use a stopper to slow down the flow of water/ block the bottle mouth
XSTRW	Use a blade of grass/ leaf/ flower stem etc... as a straw

Table G.5

Pilot and main phase: Solution codes for the open transfer task (ball-in-the-wall problem)

Code	Description
YBYNB	Buy new ball
YCHWG	Attach chewing gum/ wet 'sticky' paint/ 'glue'/ sticky bug spray to broom/ rake/ hosepipe/ garden glove/ coin on front of hosepipe/ hands/ spade
YCRTE	Create a new ball (wrap sweets/ paint/ wrap in glove)
YFRCE	Exert force on the ball/ create pressure to 'push' the ball (e.g. spray bugspray, back of broom, throwing objects, disturbing animals)
YGLVE	Use gloves to gain extra traction
YGVUP	Give up/ do something else
YHELP	Get help from someone else (e.g. an expert, parent, younger person with smaller fingers); get someone to bring a new ball
YINVN	Invent a tool to reach into the hole by combining the available tools (e.g. putting tools inside each other, sticking tools to one another etc...)
YLBRC	Lubricate the ball/ make it slippery
YNLRG	Enlarge hole to make it shallower/ easier to reach; dig alternate or parallel hole; wet the sides so soil is moist and falls away
YPLQD	Pour liquid in the hole to float/ pressure the ball out (displacement)
YRSCH	Research what to do
YSCTN	Create suction using the hosepipe/ vacuum cleaner; buy a straw
YSELL	Sell things to get money to buy a new ball
YTOOL	Use a tool to trap the ball and pull it out (e.g. spade, rake, rake tooth, broom, hosepipe, tool handle, steel wire etc...)
YVIBR	Create vibrations by hitting the wall/ putting cellphone close

Appendix H

Table H.1

Main phase: Re-calculated internal consistency reliability for the Analogical Reasoning Task

Step	Variable	n	No. items	α
Step 1	ART Original-32	545	32	.560
	If deleted Item 7			.587
	If deleted Item 11			.560
	If deleted Item 15			.561
	If deleted Item 17			.574
	If deleted Item 21			.560
	If deleted Item 25			.582
	If deleted Item 27			.564
	If deleted Item 32			.563
Step 2	ART Stage Two-24	593	24	.619
	If deleted Item 1			.621
	If deleted Item 9			.620
	If deleted Item 13			.620
Step 3	RVRT-21	599	21	.624

ART = Analogical Reasoning Task; RVRT-21 = Revised Verbal Reasoning Task (verbal analogical reasoning)

Table H.2

Main phase: Rotated factor pattern for the revised verbal analogical reasoning task

	F1	F2	F3	F4	F5	F6	F7	F8
Item 2	.163	.201	.260	.135	.012	.168	-.453	.044
Item 3	-.004	.108	.061	.138	.691	.007	.114	.068
Item 4	-.024	.003	-.067	-.003	.219	.750	.065	-.061
Item 5	-.102	.625	.056	.051	.320	-.113	-.083	-.043
Item 6	.291	.509	-.080	.023	.106	.226	-.094	-.017
Item 8	.543	.196	-.038	.212	-.031	.077	.247	.090
Item 10	.121	.345	.365	.263	-.077	.010	-.115	-.005
Item 12	.132	.046	-.028	.120	.115	.059	.664	-.039
Item 14	.157	.008	-.033	.664	-.196	.170	.060	.057
Item 16	.138	.543	.024	.030	-.171	-.076	.273	.177
Item 18	-.031	.022	.675	-.094	.087	.006	-.100	.102
Item 19	.090	.045	.063	.096	.124	.028	-.026	.866
Item 20	.075	-.025	-.042	.549	.224	.045	-.094	.084
Item 22	-.002	.088	.140	.050	-.145	.713	-.050	.078
Item 23	.327	.328	.101	-.123	.453	.094	-.073	-.011
Item 24	.682	-.028	.136	-.043	.051	-.093	-.112	.217
Item 26	-.043	.034	.571	-.050	-.048	.038	.525	.089
Item 28	.292	-.117	.553	.183	.146	.077	-.038	-.354
Item 29	-.114	.138	.095	.584	.163	-.183	.132	-.072
Item 30	.462	-.236	.016	.142	.471	.085	.033	.132
Item 31	.582	.181	.003	.032	.047	-.018	.032	-.209
	$\alpha=.383$	$\alpha=.295$	$\alpha=.287$	$\alpha=.279$	$\alpha=.431$	$\alpha=.305$	$\alpha=.027$	-

Table H.3

Main phase: Item difficulties (p-values) for the Raven's Advanced Progressive Matrices

	n	Correct	%	p-value		n	Correct	%	p-value
Item 1	655	586	89.5	.895	Item 19	654	413	63.1	.631
Item 2	655	602	91.9	.919	Item 20	655	330	50.4	.504
Item 3	654	594	90.8	.908	Item 21	654	307	46.9	.469
Item 4	654	589	90.1	.901	Item 22	653	215	32.9	.329
Item 5	655	562	85.8	.858	Item 23	651	265	40.7	.407
Item 6	654	585	89.4	.894	Item 24	653	189	28.9	.289
Item 7	653	540	82.7	.827	Item 25	655	242	36.9	.369
Item 8	654	542	82.9	.829	Item 26	652	249	38.2	.382
Item 9	655	563	86.0	.860	Item 27	651	202	31.0	.310
Item 10	653	456	69.8	.698	Item 28	651	144	22.1	.221
Item 11	655	558	85.2	.852	Item 29	654	146	22.3	.223
Item 12	654	534	81.7	.817	Item 30	653	212	32.5	.325
Item 13	655	414	63.2	.632	Item 31	652	161	24.7	.247
Item 14	653	496	76.0	.760	Item 32	654	132	20.2	.202
Item 15	654	462	70.6	.706	Item 33	651	207	31.8	.318
Item 16	653	443	67.8	.678	Item 34	651	155	23.8	.238
Item 17	654	491	75.1	.751	Item 35	652	110	16.9	.169
Item 18	654	301	46.0	.460	Item 36	651	48	7.4	.074

Table H.4

Main phase: Item difficulties (p-values) for the revised verbal analogical reasoning task

RVRT-21	n	Correct	%	p-value
Item 1 (2)	655	518	79.1	.791
Item 2 (3)	649	535	82.4	.824
Item 3 (4)	654	586	89.6	.896
Item 4 (5)	654	390	59.6	.596
Item 5 (6)	653	546	83.6	.836
Item 6 (8)	656	610	93.0	.930
Item 7 (10)	654	536	82.0	.820
Item 8 (12)	654	639	97.7	.977
Item 9 (14)	654	426	65.1	.651
Item 10 (16)	656	576	87.8	.878
Item 11 (18)	654	603	92.2	.922
Item 12 (19)	656	424	64.6	.646
Item 13 (20)	639	322	50.4	.504
Item 14 (22)	654	569	87.0	.870
Item 15 (23)	653	483	74.0	.740
Item 16 (24)	656	615	93.8	.938
Item 17 (26)	655	635	96.9	.969
Item 18 (28)	656	572	87.2	.872
Item 19 (29)	646	173	26.8	.268
Item 20 (30)	645	548	85.0	.850
Item 21 (31)	656	625	95.3	.953

RVRT-21 = Revised Verbal Reasoning Task (verbal analogical reasoning)

Table H.5

Main phase: Descriptive statistics for individual heuristic strategy preference items

Variable	n	Missing	Mean	Std. Dev.	Min.	Max.	Skewness	Kurtosis
HSP 1	639	19	3.38	1.042	1	5	-0.238	-0.424
HSP 2	644	14	3.67	1.008	1	5	-0.541	-0.123
HSP 3	642	16	3.75	1.022	1	5	-0.690	0.133
HSP 4	647	11	2.95	1.217	1	5	0.030	-0.920
HSP 5	644	14	3.25	1.187	1	5	-0.222	-0.839
HSP 6	646	12	3.71	1.188	1	5	-0.542	-0.713
HSP 7	648	10	3.71	0.995	1	5	-0.486	-0.216
HSP 8	646	12	3.48	1.154	1	5	-0.438	-0.597
HSP 9	646	12	4.33	0.846	1	5	-1.244	1.261
HSP 10	646	12	3.52	1.020	1	5	-0.367	-0.324
HSP 11	648	10	3.10	1.212	1	5	-0.047	-0.917
HSP 12	647	11	3.73	0.999	1	5	-0.524	-0.192
HSP 13	645	13	3.51	1.137	1	5	-0.375	-0.700
HSP 14	643	15	3.69	1.112	1	5	-0.562	-0.441
HSP 15	644	14	3.52	1.063	1	5	-0.403	-0.378
HSP 16	646	12	3.00	1.265	1	5	0.041	-1.041
HSP 17	643	15	3.40	1.107	1	5	-0.430	-0.461
HSP 18	642	16	3.54	1.052	1	5	-0.361	-0.496
HSP 19	648	10	3.04	1.291	1	5	-0.081	-1.098
HSP 20	647	11	3.48	1.007	1	5	-0.261	-0.479

HSP = heuristic strategy preference

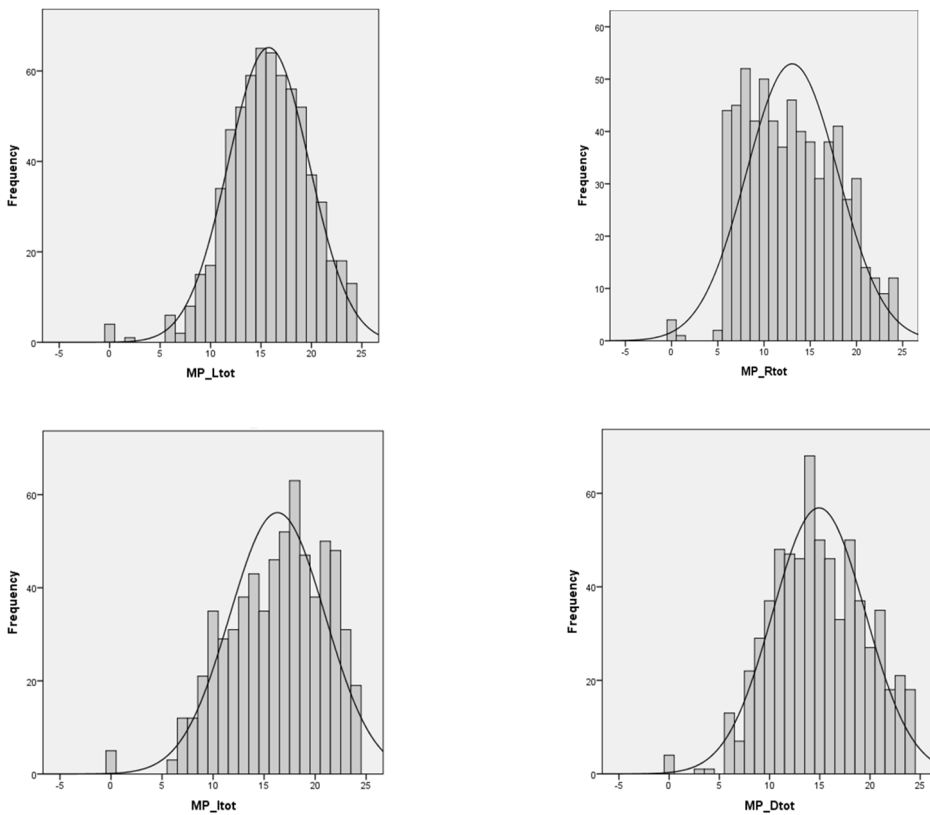


Figure H.1. Histograms for modal preference (listening, reading, iconic, direct experience)

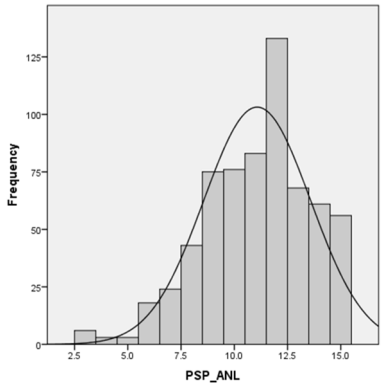
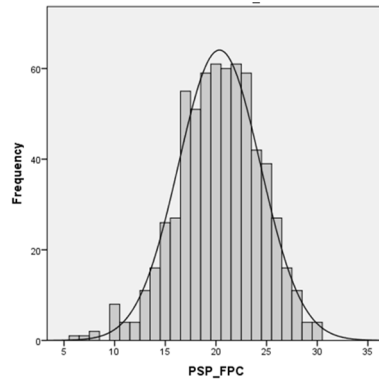
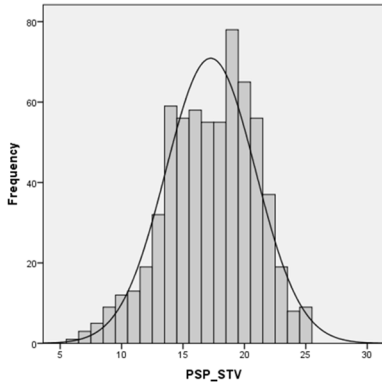


Figure H.2. Histograms for heuristic strategy preference (step-by-step/visualisation, free production/combining, and analogy)

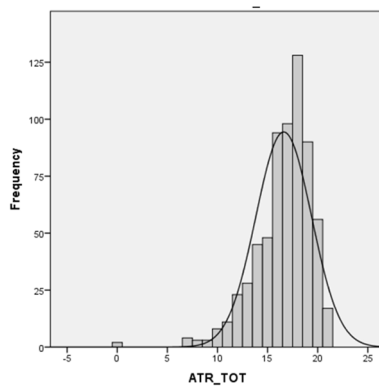
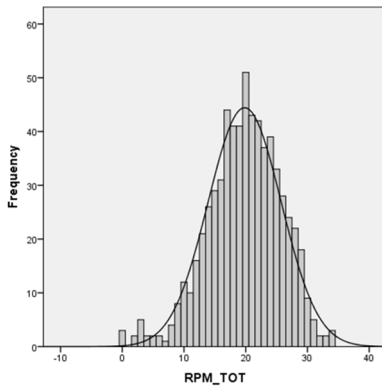


Figure H.3. Histograms for analogical reasoning (non-verbal (RAPM) and verbal (RVRT-21))

Appendix I

Table I.1

Main phase: Solution category frequencies for the directed analogical transfer task (n = 608)

Category	n	%	Category	n	%
ANS1RI	374	61.5	ANS1DLS	162	26.6
ANS2ML	316	52.0	ANS1DP	184	30.3
ANS3CD	181	29.8	ANS2TRC	38	6.3
ANS4SS	43	7.1			
NADPT	40	6.6	NPNTTL	1	0.2
NADPTP	18	3.0	NPOST	31	5.1
NADJT	30	4.9	NREFL	48	7.9
NARTF	32	5.3	NREMV	45	7.4
NBARR	35	5.8	NROOM	30	4.9
NFLOR	104	17.1	NROOML	28	4.6
NGOGG	28	4.6	NRSCH	23	3.8
NGOGGS	10	1.6	NSENS	29	4.8
NLCVR	47	7.7	NSNRF	72	11.8
NLITK	26	4.3	NTINT	19	3.1
NLRGE	9	1.5	NTMPC	71	11.7
NPICT	10	1.6	NVISH	96	15.8
NPNTT	14	2.3			

A = analogical; N = non-analogical

ANS1RI = reduced intensity; ANS1DLS = different light types; ANS1DP = different light positions; ANS2ML = multiple lights; ANS2TRC = independent lights/torches; ANS3CD = circular disposition; ANS4SS = simultaneous summation

NADPT = genetic adaptation; NADPTP = adaptation process; NADJT = adjustable lighting; NARTF = artificial stock; NBARR = barriers in tank; NFLOR = fluorescence; NGOGG = night vision goggles; NGOGGS = camera system; NLCVR = light covering; NLITK = light inside tank; NLRGE = larger replica; NPICT = pictures/ models; NPNTT = paint room dark; NPNTTL = paint room light; NPOST = change replica positioning; NREFL = reflective surfaces; NREMV = remove fish; NRSCH = expert assistance; NROOM = dark room; NROOML = well-lit room; NSENS = controlled lighting; NSNRF = skylight/sunroof; NTINT = tinted windows; NTMPC = temperature control; NVISH = visiting hours

Table I.2

Main phase: Solution category frequencies for the open analogical transfer task
(*n* = 592)

Category	n (Bird)	% (Bird)	Category	n (Ball)	% (Ball)
XALTW	52	8.8	YBYNB	71	12.0
XANGL	102	17.2	YCHWG	397	67.1
XBRKB	44	7.4	YCRTE	25	4.2
XCTCH	158	26.7	YFRCE	65	11.0
XDEWR	49	8.3	YGLVE	29	4.9
XDIPP	53	9.0	YGVUP	20	3.4
XEATS	146	24.7	YHELP	125	21.1
XHELP	13	2.2	YINVN	37	6.2
XHOLE	127	21.5	YLBRC	13	2.2
XHRZN	102	17.2	YNLRG	146	24.7
XINCL	104	17.6	YPLQD	397	67.1
XKOVN	213	36.0	YRSCH	5	0.8
XPEBB	157	26.5	YSCTN	42	7.1
XREST	18	3.0	YSELL	16	2.7
XROLL	39	6.6	YTOOL	223	37.7
XSHPB	11	1.9	YVIBR	7	1.2
XSTPR	9	1.5			
XSTRW	64	10.8			

X = thirsty bird; Y = ball-in-the-wall

XALTW = alternate water source; XANGL = angle/ tilt bottle; XBRKB = break bottle; XCTCH = catchment device; XDEWR = dew/ rain; XDIPP = use dipper; XEATS = eat other; XHELP = get help; XHOLE = make a hole; XHRZN = place horizontally; XINCL = create incline; XKOVN = knock bottle over; XPEBB = pebble displacement; XREST = rest; XROLL = roll/ shake bottle; XSHPB = change bottle shape; XSTPR = use stopper; XSTRW = create a straw

YBYNB = buy new ball; YCHWG = chewing gum and pole; YCRTE = create a new ball; YFRCE = exert force/ pressure; YGLVE = use gloves; YGVUP = give up; YHELP = get help; YINVN = invent a tool; YLBRC = lubricate the ball; YNLRG = enlarge the hole ; YPLQD = pour liquid; YRSCH = do research; YSCTN = create suction; YSELL = selling objects; YTOOL = use a tool; YVIBR = creating vibrations

Appendix J

Table J.1

Main phase: Observed values for directed analogical transfer and categorical non-verbal analogical reasoning (RAPM-2)

		RAPM-2		Total
		(non-verbal analogical reasoning)		
		1	2	
Directed transfer	0	104 (17.1)	86 (14.1)	190 (31.3)
	1	119 (19.6)	110 (18.1)	229 (37.7)
	2	92 (15.1)	97 (16.0)	189 (31.1)
Total		315 (51.8)	293 (48.2)	608 (100)

Table J.2

Main phase: Observed values for open analogical transfer and categorical non-verbal analogical reasoning (RAPM-2)

		RAPM-2		Total
		(non-verbal analogical reasoning)		
		1	2	
Open transfer	0	224 (37.8)	174 (29.4)	398 (67.2)
	1	83 (14.0)	111 (18.8)	194 (32.8)
Total		307 (51.9)	285 (48.1)	592 (100)

Table J.3

Main phase: Observed values for directed analogical transfer and categorical verbal analogical reasoning (RVRT-2)

		RVRT-2		Total
		(verbal analogical reasoning)		
		1	2	
Directed transfer	0	121 (19.9)	69 (11.3)	190 (31.3)
	1	122 (20.1)	107 (17.6)	229 (37.7)
	2	84 (13.8)	105 (17.3)	189 (31.1)
Total		327 (53.8)	281 (46.2)	608 (100)

Table J.4

Main phase: Observed values for open analogical transfer and categorical verbal analogical reasoning (RVRT-2)

		RVRT-2 (verbal analogical reasoning)		Total
		1	2	
Open transfer	0	243 (41.0)	155 (26.2)	398 (67.2)
	1	77 (13.0)	117 (19.8)	194 (32.8)
Total		320 (54.1)	272 (45.9)	592 (100)

Table J.5

Main phase: One-way ANOVAs for directed transfer and heuristic preference items

Directed transfer	Levene's	SS	df	MS	F	p	η^2
HSP 1	.359	4.307 638.335	2 589	2.153 1.084	1.987	.138	.007
HSP 2	.422	0.268 594.399	2 594	0.134 1.001	0.134	.875	.000
HSP 3	.943	1.281 625.334	2 591	0.640 1.058	0.605	.546	.002
HSP 4	.251	6.257 884.615	2 596	3.128 1.484	2.108	.122	.007
HSP 5	.561	0.540 841.272	2 594	0.270 1.416	0.191	.826	.001
HSP 6	.843	5.045 850.374	2 595	2.523 1.429	1.765	.172	.006
HSP 7	.722	1.072 591.301	2 597	0.536 0.990	0.541	.582	.002
HSP 8	.462	4.212 780.746	2 595	2.106 1.312	1.605	.202	.005
HSP 10	.177	1.932 611.541	2 595	0.966 1.028	0.940	.391	.003
HSP 11	.268	2.635 860.884	2 597	1.317 1.442	0.914	.402	.003
HSP 12	.430	2.065 582.122	2 596	1.032 0.977	1.057	.348	.004
HSP 13	.436	8.153 753.086	2 594	4.077 1.268	3.215	.041	.011
HSP 14	.028	3.475 746.568	2 592	1.738 1.261	1.378	.253	.005
HSP 15	.830	1.471 657.759	2 594	0.735 1.107	0.664	.515	.002
HSP 16	.033	2.090 947.850	2 595	1.045 1.593	0.656	.519	.002
HSP 17	.400	13.895 710.233	2 593	6.947 1.198	5.801	.003	.019
HSP 18	.401	3.709 649.900	2 591	1.855 1.100	1.686	.186	.006
HSP 19	.447	3.732 979.226	2 597	1.866 1.640	1.138	.321	.004
HSP 20	.659	1.208 576.282	2 596	0.604 0.967	0.624	.536	.002

HSP = heuristic strategy preference

Table J.6

Main phase: Kruskal-Wallis H test for directed transfer and heuristic preference Item 9

Directed transfer	X ²	df	p
HSP 9	0.121	2	.941

HSP = heuristic strategy preference

Table J.7

Main phase: Independent samples t-tests for open transfer and heuristic preference items

Open transfer	Levene's	t	df	p	d	Lower CI	Upper CI
HSP 1	.522	1.283	578	.200	.115	-0.063	0.299
HSP 2	.528	-0.481	582	.631	.051	-0.214	0.130
HSP 3	.113	1.049	581	.295	.096	-0.083	0.275
HSP 4	.861	-2.117	585	.035	.181	-0.435	-0.016
HSP 5	.871	-0.837	583	.403	.077	-0.290	0.117
HSP 6	.268	1.429	584	.154	.125	-0.056	0.355
HSP 7	.088	-1.014	586	.311	.092	-0.258	0.082
HSP 8	.500	0.172	584	.863	.009	-0.179	0.213
HSP 10	.319	-0.605	584	.545	.060	-0.229	0.121
HSP 11	.738	2.137	586	.033	.190	0.018	0.435
HSP 12	.006	-1.568	430.472	.118	.134	-0.294	0.033
HSP 13	.359	1.324	583	.186	.124	-0.064	0.329
HSP 14	.520	-0.272	582	.785	.027	-0.222	0.168
HSP 15	.161	0.696	582	.487	.067	-0.118	0.247
HSP 16	.626	1.161	584	.246	.103	-0.090	0.348
HSP 17	.018	-2.169	426.723	.031	.193	-0.388	-0.019
HSP 18	.498	1.172	581	.241	.104	-0.074	0.293
HSP 19	.445	0.728	586	.467	.063	-0.140	0.304
HSP 20	.215	1.560	586	.119	.143	-0.035	0.307

HSP = heuristic strategy preference

Table J.8

Main phase: Mann-Whitney U test for open transfer and heuristic preference Item 9

Open transfer	MWU	Z	Sig	r (ES)
HSP 9	37030.00	-0.512	.609	.021

HSP = heuristic strategy preference

Table J.9

Main phase: Observed values for directed analogical transfer and gender

		Gender		Total
		1	2	
Directed transfer	0	65 (10.7)	125 (20.6)	190 (31.3)
	1	59 (9.7)	170 (28.0)	229 (37.7)
	2	36 (5.9)	153 (25.2)	189 (31.1)
Total		160 (26.3)	448 (73.7)	608 (100)

Table J.10

Main phase: Observed values for directed analogical transfer and home language

		Home language		Total
		1	2	
Directed transfer	0	90 (14.8)	99 (16.3)	189 (31.1)
	1	136 (22.4)	93 (15.3)	229 (37.7)
	2	136 (22.4)	53 (8.7)	189 (31.1)
Total		362 (59.6)	245 (40.4)	607 (100)

Table J.11

Main phase: Observed values for directed analogical transfer and type of schooling

		Type of schooling		Total
		1	2	
Directed transfer	0	109 (18.5)	73 (12.4)	182 (30.8)
	1	115 (19.5)	107 (18.1)	222 (37.6)
	2	92 (15.6)	94 (15.9)	186 (31.5)
Total		316 (53.6)	274 (46.4)	590 (100)

Table J.12

Main phase: Observed values for directed analogical transfer and socioeconomic status

		Socioeconomic status			Total
		1	2	3	
Directed transfer	0	77 (12.7)	55 (9.0)	58 (9.5)	190 (31.3)
	1	83 (13.7)	70 (11.5)	76 (12.5)	229 (37.7)
	2	44 (7.2)	69 (11.3)	76 (12.5)	189 (31.1)
Total		204 (33.6)	194 (31.9)	210 (34.5)	608 (100)

Table J.13

Main phase: Observed values for open analogical transfer and gender

		Gender		Total
		1	2	
Open transfer	0	98 (16.6)	300 (50.7)	398 (67.2)
	1	54 (9.1)	140 (23.6)	194 (32.8)
Total		152 (25.7)	440 (74.3)	592 (100)

Table J.14

Main phase: Observed values for open analogical transfer and home language

		Home language		Total
		1	2	
Open transfer	0	212 (35.9)	185 (31.3)	397 (67.2)
	1	136 (23.0)	58 (9.8)	194 (32.8)
Total		348 (58.9)	243 (41.1)	591 (100)

Table J.15

Main phase: Observed values for open analogical transfer and type of schooling

		Type of schooling		Total
		1	2	
Open transfer	0	234 (40.7)	151 (26.3)	385 (67.0)
	1	73 (12.7)	117 (20.3)	190 (33.0)
Total		307 (53.4)	268 (46.6)	575 (100)

Table J.16

Main phase: Observed values for open analogical transfer and socioeconomic status

		Socioeconomic status			Total
		1	2	3	
Open transfer	0	155 (26.2)	128 (21.7)	114 (19.3)	397 (67.2)
	1	49 (8.3)	57 (9.6)	88 (14.9)	194 (32.8)
Total		204 (34.5)	185 (31.3)	202 (34.2)	591 (100)

Appendix K

Table K.1

Main phase: Case processing summary – directed transfer model one (home language)

		n	M %
Directed transfer	0	187	31.2
	1	225	37.5
	2	188	31.3
RVRT-2	1	322	53.7
	2	278	46.3
Gender	1	157	26.2
	2	443	73.8
Home language	1	359	59.8
	2	241	40.2
Valid		600	100
Missing		58	
Total		658	
Subpopulation		597	

RVRT-2 = Revised Verbal Analogical Reasoning Task
(verbal analogical reasoning - dichotomous)

Table K.2

Main phase: Individual predictors for directed transfer model one (home language)

		B	Std. Error	Wald	df	p	Exp. (B)	Lower CI	Upper CI
Dir.	Intercept	0.045	0.796	0.003	1	.955	.	.	.
T.	RAPM	0.031	0.018	3.063	1	.080	1.031	0.996	1.067
L1	ST/V	-0.073	0.032	5.246	1	.022	0.929	0.873	0.989
	F/PC	0.046	0.028	2.648	1	.104	1.047	0.991	1.107
	ANL	-0.005	0.042	0.016	1	.900	0.995	0.916	1.080
	RVRT=1	-0.247	0.218	1.274	1	.259	0.781	0.509	1.199
	RVRT=2	0	.	.	0	.	.	.	.
	GDR=1	-0.494	0.225	4.833	1	.028	0.610	0.393	0.948
	GDR=2	0	.	.	0	.	.	.	.
	HL=1	0.406	0.213	3.654	1	.056	1.501	0.990	2.277
	HL=2	0	.	.	0	.	.	.	.
	Dir.	Intercept	0.108	0.860	0.016	1	.900	.	.
T.	RAPM	0.025	0.019	1.716	1	.190	1.025	0.988	1.064
L2	ST/V	-0.092	0.034	7.356	1	.007	0.912	0.854	0.975
	F/PC	0.035	0.030	1.367	1	.242	1.035	0.977	1.098
	ANL	0.023	0.046	0.244	1	.622	1.023	0.935	1.119
	RVRT=1	-0.513	0.231	4.923	1	.027	0.598	0.380	0.942
	RVRT=2	0	.	.	0	.	.	.	.
	GDR=1	-0.954	0.254	14.049	1	.000	0.385	0.234	0.634
	GDR=2	0	.	.	0	.	.	.	.
	HL=1	0.925	0.234	15.671	1	.000	2.522	1.595	3.987
HL=2	0	.	.	0	.	.	.	.

The reference category is: 0

RAPM = Raven's Advanced Progressive Matrices (non-verbal analogical reasoning); RVRT = Revised Verbal Analogical Reasoning Task (verbal analogical reasoning - dichotomous); ST/V = step-by-step/ visualisation heuristic strategy preference; FP/C = free production/ combining heuristic strategy preference; ANL = analogy heuristic preference; GDR = gender; HL = home language

Table K.3

Main phase: Case processing summary –
directed transfer model two (type of schooling)

		n	M %
Directed transfer	0	180	30.8
	1	219	37.5
	2	185	31.7
RVRT-2	1	309	52.9
	2	275	47.1
Gender	1	154	26.4
	2	430	73.6
Type of schooling	1	312	53.4
	2	272	46.6
Valid		584	100
Missing		74	
Total		658	
Subpopulation		581	

RVRT-2 = Revised Verbal Analogical Reasoning Task
(verbal analogical reasoning - dichotomous)

Table K.4

Main phase: Individual predictors for directed transfer model two (type of schooling)

		B	Std. Error	Wald	df	p	Exp. (B)	Lower CI	Upper CI
Dir.	Intercept	0.360	0.790	0.208	1	.649	.	.	.
T.	RAPM	0.029	0.018	2.578	1	.108	1.029	0.994	1.066
L1	ST/V	-0.063	0.032	3.779	1	.052	0.939	0.882	1.001
	F/PC	0.045	0.029	2.480	1	.115	1.046	0.989	1.106
	ANL	-0.008	0.043	0.032	1	.859	0.992	0.913	1.079
	RVRT=1	-0.326	0.217	2.261	1	.133	0.722	0.472	1.104
	RVRT=2	0	.	.	0	.	.	.	.
	GDR=1	-0.503	0.227	4.935	1	.026	0.605	0.388	0.942
	GDR=2	0	.	.	0	.	.	.	.
	TSC=1	-0.258	0.208	1.533	1	.216	0.772	0.513	1.162
	TSC=2	0	.	.	0	.	.	.	.
	Dir.	Intercept	1.163	0.831	1.958	1	.162	.	.
T.	RAPM	0.026	0.019	1.765	1	.184	1.026	0.988	1.066
L2	ST/V	-0.083	0.034	6.112	1	.013	0.920	0.861	0.983
	F/PC	0.017	0.030	0.345	1	.557	1.018	0.960	1.078
	ANL	0.017	0.046	0.141	1	.708	1.017	0.930	1.112
	RVRT=1	-0.643	0.228	7.985	1	.005	0.526	0.336	0.821
	RVRT=2	0	.	.	0	.	.	.	.
	GDR=1	-0.897	0.252	12.714	1	.000	0.408	0.249	0.668
	GDR=2	0	.	.	0	.	.	.	.
	TSC=1	-0.309	0.219	1.979	1	.159	0.734	0.478	1.129
TSC=2	0	.	.	0	.	.	.	.

The reference category is: 0

RAPM = Raven's Advanced Progressive Matrices (non-verbal analogical reasoning); RVRT = Revised Verbal Analogical Reasoning Task (verbal analogical reasoning - dichotomous); ST/V = step-by-step/ visualisation heuristic strategy preference; FP/C = free production/ combining heuristic strategy preference; ANL = analogy heuristic preference; GDR = gender; TSC = type of schooling

Table K.5

Main phase: Case processing summary – directed transfer model three (socioeconomic status)

		n	M %
Directed transfer	0	188	31.3
	1	225	37.4
	2	188	31.3
RVRT-2	1	323	53.7
	2	278	46.3
Gender	1	158	26.3
	2	443	73.7
Socioeconomic status	1	200	33.3
	2	192	31.9
	3	209	34.8
Valid		601	100
Missing		57	
Total		658	
Subpopulation		601	

RVRT-2 = Revised Verbal Analogical Reasoning Task (verbal analogical reasoning - dichotomous)

Table K.6

Main phase: Individual predictors for directed transfer model three (socioeconomic status)

		B	Std. Error	Wald	df	p	Exp. (B)	Lower CI	Upper CI
Dir.	Intercept	0.497	0.781	0.405	1	.525	.	.	.
T.	RAPM	0.033	0.018	3.443	1	.064	1.033	0.998	1.069
L1	ST/V	-0.075	0.032	5.510	1	.019	0.928	0.872	0.988
	F/PC	0.036	0.028	1.690	1	.194	1.037	0.982	1.095
	ANL	-0.003	0.042	0.005	1	.943	0.997	0.918	1.083
	RVRT=1	-0.327	0.215	2.305	1	.129	0.721	0.473	1.100
	RVRT=2	0	.	.	0	.	.	.	.
	GDR=1	-0.491	0.223	4.830	1	.028	0.612	0.395	0.948
	GDR=2	0	.	.	0	.	.	.	.
	SES=1	-0.071	0.247	0.082	1	.775	0.932	0.575	1.511
	SES=2	-0.007	0.256	0.001	1	.980	0.993	0.601	1.641
	SES=3	0	.	.	0	.	.	.	.
	Dir.	Intercept	1.245	0.837	2.212	1	.137	.	.
T.	RAPM	0.026	0.019	1.802	1	.179	1.026	0.988	1.065
L2	S/TV	-0.097	0.034	8.283	1	.004	0.908	0.850	0.970
	F/PC	0.022	0.029	0.562	1	.453	1.022	0.965	1.083
	ANL	0.023	0.045	0.248	1	.619	1.023	0.936	1.118
	RVRT=1	-0.625	0.227	7.552	1	.006	0.535	0.343	0.836
	RVRT=2	0	.	.	0	.	.	.	.
	GDR=1	-0.893	0.252	12.550	1	.000	0.409	0.250	0.671
	GDR=2	0	.	.	0	.	.	.	.
	SES=1	-0.648	0.271	5.737	1	.017	0.523	0.308	0.889
	SES=2	-0.007	0.259	0.001	1	.980	0.993	0.598	1.651
SES=3	0	.	.	0	.	.	.	.

The reference category is: 0

RAPM = Raven's Advanced Progressive Matrices (non-verbal analogical reasoning); RVRT = Revised Verbal Analogical Reasoning Task (verbal analogical reasoning - dichotomous); ST/V = step-by-step/ visualisation heuristic strategy preference; FP/C = free production/ combining heuristic strategy preference; ANL = analogy heuristic preference; GDR = gender; SES = socioeconomic status

Table K.7

Main phase: Case processing summary –
open transfer model one (home language)

		n	M %
Open transfer	0	394	67.0
	1	194	33.0
RVRT-2	1	317	53.9
	2	271	46.1
Gender	1	150	25.5
	2	438	74.5
Home language	1	347	59.0
	2	241	41.0
Valid		588	100
Missing		70	
Total		658	
Subpopulation		585	

RVRT-2 = Revised Verbal Analogical Reasoning Task
(verbal analogical reasoning - dichotomous)

Table K.8

Main phase: Individual predictors for directed transfer model one (home language)

		B	Std. Error	Wald	df	p	Exp. (B)	Lower CI	Upper CI
Op. T. L1	Intercept	-1.949	0.744	6.862	1	.009**	.	.	.
	RAPM	0.029	0.016	3.159	1	.076	1.029	0.997	1.063
	ST/V	0.011	0.028	0.157	1	.692	1.011	0.957	1.069
	F/PC	-0.010	0.025	0.172	1	.678	0.990	0.942	1.039
	ANL	0.058	0.040	2.146	1	.143	1.060	0.980	1.146
	RVRT=1	-0.634	0.193	10.774	1	.001	0.530	0.363	0.774
	RVRT=2	0	.	.	0	.	.	.	.
	GDR=1	0.096	0.207	0.215	1	.643	1.101	0.734	1.652
	GDR=2	0	.	.	0	.	.	.	.
	HL=1	0.498	0.200	6.200	1	.013	1.645	1.112	2.434
	HL=2	0	.	.	0	.	.	.	.

The reference category is: 0

RAPM = Raven's Advanced Progressive Matrices (non-verbal analogical reasoning); RVRT = Revised Verbal Analogical Reasoning Task (verbal analogical reasoning - dichotomous); ST/V = step-by-step/ visualisation heuristic strategy preference; FP/C = free production/ combining heuristic strategy preference; ANL = analogy heuristic preference; GDR = gender; HL = home language

Table K.9

*Main phase: Case processing summary –
open transfer model two (type of schooling)*

		n	M %
Open transfer	0	382	66.8
	1	190	33.2
RVRT-2	1	305	53.3
	2	267	46.7
Gender	1	148	25.9
	2	424	74.1
Type of schooling	1	305	53.3
	2	267	46.7
Valid		572	100
Missing		86	
Total		658	
Subpopulation		569	

RVRT-2 = Revised Verbal Analogical Reasoning Task
(verbal analogical reasoning - dichotomous)

Table K.10

Main phase: Individual predictors for directed transfer model two (type of schooling)

		B	Std. Error	Wald	df	p	Exp. (B)	Lower CI	Upper CI
Op.	Intercept	-1.109	0.728	2.324	1	.127	.	.	.
T.	RAPM	0.032	0.017	3.712	1	.054	1.033	0.999	1.067
L1	ST/V	0.006	0.029	0.042	1	.837	1.006	0.950	1.065
	F/PC	-0.012	0.026	0.217	1	.641	0.988	0.940	1.039
	ANL	0.053	0.041	1.634	1	.201	1.054	0.972	1.142
	RVRT=1	-0.684	0.194	12.481	1	.000	0.505	0.345	0.738
	RVRT=2	0	.	.	0	.	.	.	.
	GDR=1	0.172	0.212	0.658	1	.417	1.187	0.784	1.798
	GDR=2	0	.	.	0	.	.	.	.
	TSC=1	-0.813	0.188	18.805	1	.000	0.443	0.307	0.640
	TSC=2	0	.	.	0	.	.	.	.

The reference category is: 0

RAPM = Raven's Advanced Progressive Matrices (non-verbal analogical reasoning); RVRT = Revised Verbal Analogical Reasoning Task (verbal analogical reasoning - dichotomous); ST/V = step-by-step/ visualisation heuristic strategy preference; FP/C = free production/ combining heuristic strategy preference; ANL = analogy heuristic preference; GDR = gender; TSC = type of schooling

Table K.11

Main phase: Case processing summary – open transfer model three (socioeconomic status)

		n	M %
Open transfer	0	394	67.0
	1	194	33.0
RVRT-2	1	317	53.9
	2	271	46.1
Gender	1	150	25.5
	2	438	74.5
Socioeconomic status	1	202	34.4
	2	184	31.3
	3	202	34.4
Valid		588	100
Missing		70	
Total		658	
Subpopulation		588	

RVRT-2 = Revised Verbal Analogical Reasoning Task
(verbal analogical reasoning - dichotomous)

Table K.12

Main phase: Individual predictors for open transfer model three (socioeconomic status)

		B	Std. Error	Wald	df	p	Exp. (B)	Lower CI	Upper CI
Op. T. L1	Intercept	-1.052	0.719	2.142	1	.143	.	.	.
	RAPM	0.028	0.016	3.016	1	.082	1.029	0.996	1.062
	ST/V	0.005	0.028	0.034	1	.853	1.005	0.951	1.063
	F/PC	-0.012	0.025	0.241	1	.624	0.988	0.941	1.037
	ANL	0.052	0.040	1.737	1	.188	1.054	0.975	1.139
	RVRT=1	-0.666	0.191	12.170	1	.000	0.514	0.353	0.747
	RVRT=2	0	.	.	0	.	.	.	.
	GDR=1	0.163	0.209	0.607	1	.436	1.177	0.781	1.773
	GDR=2	0	.	.	0	.	.	.	.
	SES=1	-0.696	0.226	9.470	1	.002	0.499	0.320	0.777
	SES=2	-0.480	0.219	4.819	1	.028	0.619	0.403	0.950
	SES=3	0	.	.	0	.	.	.	.

The reference category is: 0

RAPM = Raven's Advanced Progressive Matrices (non-verbal analogical reasoning); RVRT = Revised Verbal Analogical Reasoning Task (verbal analogical reasoning - dichotomous); ST/V = step-by-step/ visualisation heuristic strategy preference; FP/C = free production/ combining heuristic strategy preference; ANL = analogy heuristic preference; GDR = gender; SES = socioeconomic status

Appendix L

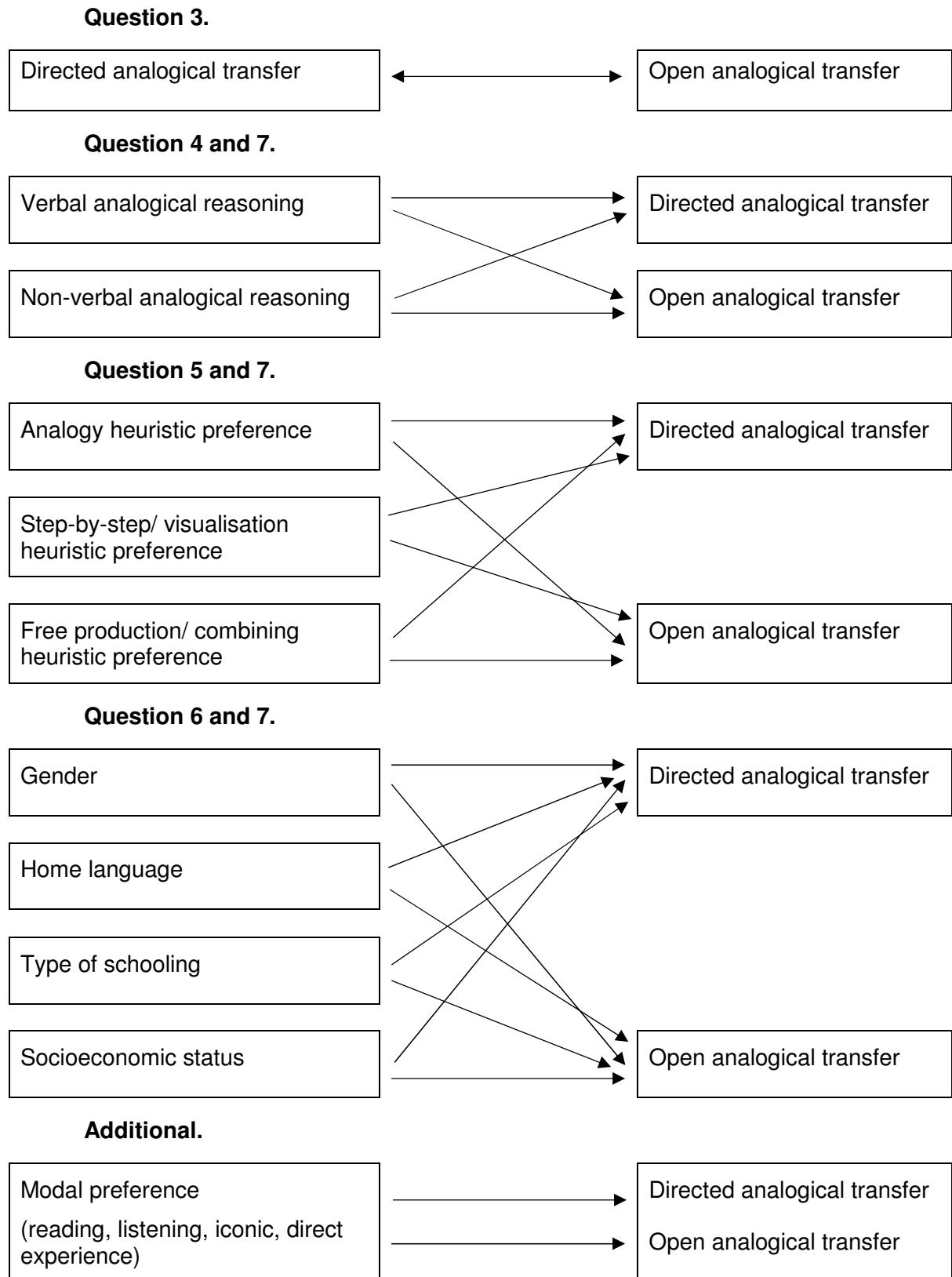


Figure L.1. Graphic representation of the key relationships explored in the study.