Effects of Incentives on Group Problem Solving Processes and Paths

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Incentives have been known to affect group performance when solving complex problems. Groups that are given individual incentives for solving problems are able to solve problems quicker, and with less errors compared to those that are given group incentives. However, much is unknown about the underlying cognitive and social factors that influence problem solving in conjunction with incentives. Research has neglected to investigate the process by which groups move from an initial problem state to the solution state. There is a heavy involvement of coordination between members, even between a heterogenous group where members have their own individual goals. Groups must first agree upon a solution, or goal state, and members must solve their own sub-goals in conjunction with one another to ensure there is no conflict or overlap. This research explores the different routes that groups with varying incentive structures take when solving a complex problem.

A previous study was analyzed where groups were given four cards with pictorial items and each member was asked to collect four of a kind. The study revealed that the most complex condition, detour and restructuring, showed the largest differences between incentive groups. In this condition participants could fall into blind alley categories, and must detour around these false sets in order to reach the correct solution. The solution also consisted of three similar pictorial items and one superordinate item, requiring participants to cognitively restructure their perception of the category sets. Thematic coding was done on transcripts of the experimental videos, and differences between groups were analyzed. Additional analysis was also conducted on the way each group organized their solution paths by investigating the order of category labels that groups would produce. Results showed that groups given individual incentives had much more organized paths, were less willing to explore the problem space, and had a better understanding of problem structure compared to groups given a group incentive. Individual

incentive groups were also more likely to move directly towards the solution, and spend less time creating category labels for incorrect category solutions. Overall, these results contribute to the problem solving research field by establishing that the behaviours and characteristics of groups solving complex problem vary not only on internal factors, such as personality type and expertise, but also based on external factors, such as incentive types.

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Chapter 1: Introduction and Literature Review

Problem solving is at the core of human innovation, policy making, negotiations and decision making. Some of today's most challenging problems hinge on heterogenous groups that are tasked with working together to create solutions despite competing interests. These members face differences in cognitive thinking styles, social aspects, and personality traits, but must find ways to create cohesive action plans. The global climate crisis, impacting both current and future generations, can only be solved by the collaboration of nations, despite their opposing economic and political interests. Geopolitical struggles such as the refugee crisis, Middle East conflicts, disputes of territories and more, arise due to competing interests of the actors involved, and can only be resolved through collaborative problem solving. In organizational settings, individuals with various roles from different departments are often assigned collaborative interdepartmental projects and must work together through the varying communication styles and knowledge that each individual has. But even when the stakes are high, groups have trouble working effectively to reach timely solutions. At the core of these issues lies a lack of understanding of the underlying processes behind group problem solving.

Existing literature has emphasized the performance of how groups and individuals solve complex problems, but there remains a large gap in knowledge of how solutions are achieved. Very little research has investigated the qualitative aspects, such as the diverse solutions paths groups take. These paths become especially important when factors that affect problem structures and group cohesion are added to a problem. Factors such as the varying motivations of each member of a group can play a major role in how groups approach a problem. When members of a group are given individual incentives, they often solve problems more efficiently but explore less of the problem space. Groups that are given incentives as a whole are more likely to engage in more creative conversation, but are prone to making more errors.

This research investigates how the relationship between incentives given to either an individual or a group effect the behaviours of problem solving groups. An experimental methodology used by Gbemisola Adejumo, 2008, and Lin Chen, 2010 was used, where groups were tasked with a collaborative problem. A thematic coding method was used to analyze various experimental videos from these methodological protocols. Then, an analysis was conducted on category labels to determine how groups arrived to the correct solution. The different cognitive and social processes of the varying group incentive types were studied. This thesis shows how group behaviour and problem solving processes differ depending on the factors acting on a problem. It is presented in the order listed below:

Chapter 1 reviews previous literature in the problem solving field and introduces the study.

Chapter 2 explains the methodology used in the current study.

Chapter 3 explains the hypotheses and results of the thematic codes.

Chapter 4 presents the analysis of the other quantitative results, the additional analysis done on groups solutions paths, and the results of groups ranked performance.

Chapter 5 discusses the overall findings of this study, identifies the limitations of the work, and suggests future research directions.

1.1 Introduction to the Literature on Problem Solving

From decision making, to negotiations, to innovation, problem solving lays at the core of our everyday lives. Because problem solving is an integral part of the modern day world, it is important to understand the factors and dynamics which make problem solving more difficult, and more efficient. Since the 1930's, problem solving has been studied in both an individual and group context in order to gain this understanding. For more simple problem solving, such as problems that have a clearly defined answer and only require a decision for a solution alternative, these types of problems are more efficiently completed by individuals (Barron, 2000, 2003; Bouchard, 1969). However, problems rarely have a clearly defined solution, and require multiple steps to complete. With these types of problems, groups are known to outperform individuals (Faust, 1959; Heller et al., 1992; Laughlin et al., 2006). In group settings, numerous factors can affect the performance of individuals who must coordinate to solve problems. Factors can include communication styles, expertise, working memory capabilities, and more (Davidson et al., 2003). The extent to which these factors affect problem solving performance varies based on the individuals themselves, and the type of group. For example, a group of physics experts can easily work together on a complex physics problem. They each have similar knowledge, communication styles, and memory load on the topic. But when the same group is asked to write an essay on outdoor gardening, challenges might begin to arise.

Everyday group problems are most commonly tackled by heterogenous groups, where a diverse set of individuals are put into a cooperative group. Each individual may have different abilities, goals, interests, and/or expertise. Problem solving can often become more challenging for heterogenous groups as the competing interests and goals of each individual can make it difficult for the group to achieve an agreed upon solution. In geopolitical conflicts such as the refugee crisis, disputes can only be solved through coordinated problem solving. In organizational settings, the lack of cooperation in group problem solving can hinder innovation and can result in a loss of productivity. No matter how high the stakes, groups have trouble working effectively to reach timely solutions. Although research has studied the performance of groups completing difficult tasks, there remains a gap in knowledge on how groups arrive to their different outcomes. At the core of this issues lies the lack of understanding of how social and cognitive processes affect group problem solving.

In this literature review, the main areas of interest in research on group problem solving will be presented. Firstly, the different problem solving approaches that have been used throughout the problem solving literature will be discussed. These include the Gestalt approach, the information processing approach, the Social Decision Scheme (SDS) approach, and the Hidden Profile approach. Then, additional research that has been done on complex group problem solving, and other work involving group incentives will be analyzed. These topics will be examined to outline the need for additional research on how heterogenous groups work together to solve a complex problem.

1.2 Problem Solving Approaches

Problem solving research has been conducted and popularized since the early 1900's. Many different approaches have been taken by researchers to understand how humans process and solve a problem. In this thesis, the term "process" refers to the movement from the initial state of a problem to the end state (solution) of a problem. As individuals and groups process a problem, there are underlying cognitive and social mechanisms at work. Cognitive mechanisms include factors such as information processing, or restructuring and detours, which will be discussed through the Gestalt approach and the Information Processing approach in this section.

Social mechanisms include how individuals within a group can influence one another, discussed in the SDS approach, or how groups are more likely to discuss shared information, discussed in the Hidden Profile approach. Each of these approaches has contributed to the problem solving field and moved the research forward, towards understanding how humans solve problems.

1.2.1 Gestalt Approach

Gestaltists approached problems and perception with the belief that the "whole is different from the sum of its parts" (Wertheimer, 1982). When approaching a problem, Gestaltists understood that the problem should be approached from the whole, rather from the individual components. As a problem is observed from the whole, relationships between the parts of the problem can be described based on the laws of perceptual organization: the laws of similarity, pragnanz, proximity, continuity, and closure. These laws describe how humans tend to perceptually understand things based on these rules, for example, the law of pragnanz states that objects in the environment are perceived in a way that makes them appear as simple as possible. As a result of these laws, Gestaltists place importance on problem perception and representation. It is only with a complete view of the problem representation that an individual can solve a problem.

Gestaltists argued against most behaviourists at the time, and proposed that problems were goal states that could only be solved with a correct perception of the problem itself (Duncker, 1945; Wertheimer, 1982). To investigate their theory, Gestaltists typically used insight problems, where the solution could only become apparent once problem solvers were able to reconstruct their perception of the problem to the correct perception. Such experiments on insight problems include the 9-dot problem (**Figure 1**), where problem solvers must reconstruct their view of the problem, causing insight (otherwise known as the “aha!” moment), which would reveal the goal state.

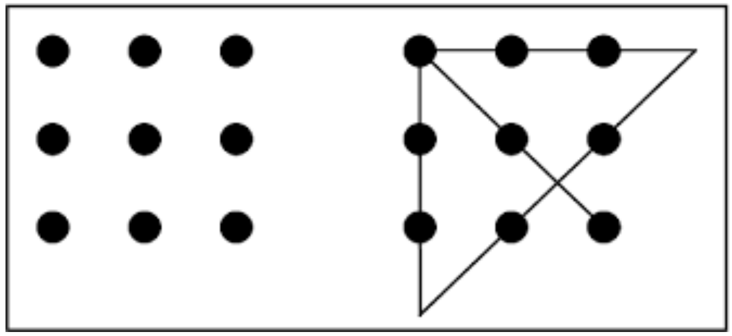

Figure 1. The 9-dot problem.

Gestaltists approach problem solving from the underlying assumption that all important components of a problem should be mentally represented, and the individual components must be viewed as interdependent (Kohler, 1969). To understand the task structure of the problem, one must perceptually understand the components of the problem, and create relationships between the problem and the solution. Kohler (1969) states that in Gestalt theory, the ability to understand the structure of the task relies on representing the problem in terms of the goal state. Although Gestaltists studied their work with insight problems, they note that not all problems are solved by insight, but they emphasize the importance of proper structuring of the problem.

The Gestalt approach also studied their theories in the context of detour problems, which also involved a type of insight. In these type of problems, the problem solver must detour, or move away from, what is seemingly the correct path towards finding the solution. For example, if a chicken were to be placed in front of a fence that was 3 feet high, and 3 feet wide, and food was put on the other side the fence, the chicken would continuously try to get through the fence. In order to reach the solution, in this case the chicken’s food, it would need to detour around the fence. This involves the chicken stepping backwards, and away from the food, in order to go around the fence. This type of detour was studied by Gestaltists in a variety of experimental contexts.

Although the Gestalt approach to problem solving has laid down a foundation for the problem solving research field, there are limitations to the approach. Gestaltists have established that problem representation, restructuring, and understanding the problem structure, are essential for problem solving, but Gestaltists have little understanding of how these phenomena occur. Research is still lacking the investigation of understanding how restructuring, or insight, occurs during problem solving. Secondly, Gestaltists mainly used insight problems to study their theories, however, this approach cannot be applied to all problem types. For example, problems that are more complex, problems that do not have one solution, or problems that have more than one solution, cannot be studied with insight experiments.

1.2.2 Information Processing Approach

The Information Processing approach to problem solving stems from Simon and Newell's (1972) Information Processing Theory. In Information Processing Theory, different types of problems were studied than those from Gestaltists. The Information Processing approach considers problem solving as a process of developing a problem space, and conducting an incremental search within the constructed problem space. Simon and Newell propose that conducting a search within a problem space can be affected by the task environment, such as the physical task environment, but also how the goal state is perceived by the problem solver.

The Information Processing Theory states that the sequence of events that occurs from the initial state to the goal state can be broken down into multiple components. The first component is the requirement of identifying the initial state and the goal state. Identifying these states allows the problem solver to be able to define the boundaries of the problem space. The larger the distance between the initial state and the goal state, the larger the problem space. Simon and Newell also highlight the importance of identifying some of the intermediate states between the initial state and goal state. Problems cannot usually be solved by simply moving from the initial state to the end state, but instead, the problem solver must explore some of the problem space and overcome the intermediate states. In order to overcome the intermediate states, the problem solver must enable "moves" to be completed, which allows the problem solver to transition from one state to another. Resources such as knowledge, skills, time, and more are needed to execute each of the moves. In the Information Processing Theory, a problem space can be reduced by exploring and search the space itself. This type of problem search can be done with information; the more of the problem's information that is obtained, the more uncertainty a problem solver can reduce. A typical example of an Information Processing approach to examining problem solving is the Tower of Hanoi problem (**Figure 2**). In the Tower of Hanoi problem, problem solvers have to perform many incremental actions to reach the goal state from the initial state.

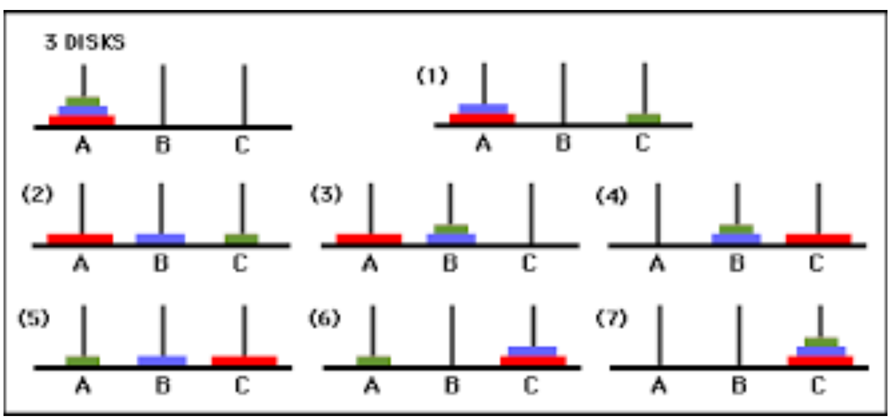

Figure 2. The Tower of Hanoi problem.

In the Tower of Hanoi problem, the initial problem state is the placement of all three disks from smallest to largest on the first peg. As the problem solver begins to move the disks around, the other possible states of the problem can be seen, and the problem space is enlarged. Since there are multiple ways that the problem can be solved, the entire problem space itself gives an understanding of the different ways that the problem can be solved, and each move that can be made, although the problem solver might not be able to see the entire problem space. Since there are multiple ways to solve the problem, but the problem solver may not be able to represent the entire problem space mentally, the problem can be classified as a difficult problem.

Memory and information sharing also play an important role in Information Processing Theory. Simon and Newell (1972) define an information processing system as a system that consists of a set of memories and informational processes. These memories interact with the information to produce inputs and outputs for the information processes. Memory is defined as an entity that represents information as a form of symbols. It is well known in current research that one of the main components involved in problem solving, and complex problem solving (Dunbar, 1998), is working memory. In working memory, we can make calculations on currently active knowledge. While solving a problem, the problem solver will develop numerous representations in their working memory as they search through the problem space. It is therefore important to include aspects of memory capacity, which can be influenced by the amount of knowledge or information that is being processed by the problem solver. The more information that must remain within working memory, the more difficult information processing, and therefore problem solving, becomes.

Information sharing is also an important aspect of the Information Processing approach. Simon (1995) notes that before a problem can begin to be solved, the problem solver must first represent all new sources of information. As new information is added, the problem solver can uncover more of the problem space and intermediate steps. However, there may be a point where the addition of new information becomes an overload on working memory and cognitive functions. For example, in a study by Riedl and Wooley (2016), the authors found that when asynchronous discussion occurs, where many different topics are being discussed by group members, there is an increase on information overload that reduces the synergy and performance of group members. This is especially true if group members are discussing a wide range of topics with diverse information. They also found that long time lapses between discussion led to a disjointed type of discussion, and groups were slower to solve the problem at hand.

Although the Information Processing approach to problem solving has significantly moved the problem solving research forward, there are some limitations to the approach. Firstly, is the need for memory capacity to process each of the incremental searches as the problem solver is solving the problem. In complex problems, it might not be possible to represent each of the possible searches. Additionally, the Information Processing approach lacks the understanding of how problem solvers conduct their searches. There has yet to be an explanation behind what is guiding the search, and the constraints that act on the different searches that problem solvers engage in while solving a problem.

1.2.3 SDS Approach

Both the Gestalt approach and Information Processing approach emphasize individual problem solving. However, in the Social Decision Scheme (SDS) approach, researchers provide a model for group decision making, and propose that groups reach a decision through the collective combination of individual solution preferences. Researchers suggest that individuals within a group can influence one another, and the consensus is usually reached after a multi-staged negotiation. This model was initially developed by the incremental work of several researchers (Laughlin, 1980, 2011; Restle & Davis, 1962; Steiner, 1966; Davis et al., 1968; Zajonc et al., 1972) to study the mechanisms that groups use, especially groups made up of diverse personnel, during decision making and problem solving processes.

In Laughlin's (2011) review on SDS, he states that exploration of SDS first emerged in the late 1940's when researchers were most interested in investigating public voting systems. Arrow (1951, 1963) and Black (1948, 1958), presented a model of the desirable characteristics of a voting system, and considered whether the parliamentary procedures of that time considered those characteristics. This model was termed "social choice theory", rather than SDS, because it centered around a focus of how groups make choices. From their findings, they noticed that social choice was a combination of individual values, and these values can ultimately affect the rationale of the groups' decision. Davis (1973), then coined the term "social decision scheme theory" when he conducted empirical experiments on group decision making. Davis' mathematical model explored predicting how a group makes a decision through probability distributions. If each individual is assigned a probability for their preference for a solution alternative, then the solution that the group might choose at the end can be mathematically calculated. The Social Decision Scheme is the combination of each of these probability distributions, where each of the member's preferences is calculated to give the collective group response. Davis then conducted experiments to test his hypothesis on mock jury groups, where groups had to decide one of two decision alternatives: the defendant is innocent or guilty of committing murder.

An important aspect of the SDS approach is that the experiments place groups in situations where members must communicate with one another until a consensus is reached

(Davis, 1973). For example, in typical SDS experiments on juries, corporate boards, and other committees, individuals must share their different perspectives until the group eventually reaches a unanimous decision. This decision might not be the "correct" response, but is ultimately one that each member of the group decides is the correct response. SDS theorizes that individuals first form their own decision preferences prior to conferring with group members, but social factors can lead individuals to change their preferences while communicating with one another. For example, if one individual is a particularly strong leader, they would be able to influence others towards their own personal preference. Alternatively, an expert might bring up knowledge that other group members were unaware of, and change the cognitive processes that the group follows to reach their decision. This highlights the importance of social factors and processes that can affect a group.

Zajonc et al., (1972) criticizes the assumption that SDS is founded on, and states that the mathematical model does not always account for the wide range of other possibilities that can affect a group. For example, the process by which a jury comes to a decision encompasses a considerably more complex social process than SDS researchers originally thought. Predicting a decision outcome by the probability distribution of each of the individuals does not take into account the social interactions or information processing of the group. Although they acknowledge the missing gaps and questions that remain, SDS researchers have yet to account for differences in outcomes due to the effects of social processes. For example, differences in group types, differences in task type, the effects of feedback, or the effects of individuals asynchronously moving through the stages of decision making and problem solving at different times, should be manipulated in SDS protocols.

1.2.4 Hidden Profile Approach

The Hidden Profile approach also examines how groups solve problems. In the research done on Hidden Profile tasks, a typical task involves a small group of 3-6 members that are asked to make a decision based on a set of given alternatives. Over the years, tasks have included selecting the best student president (Stasser & Titus, 1985), selecting the best job candidate to hire (Wittenbaum, 1998), the most optimal drug to produce (Kelly & Karau, 1999), the correct diagnosis in a medical case (Larson et al., 1996), the best company to invest in (McLeod et al., 1997), or the guilty suspect in a homicidal investigation (Stasser & Stewart, 1992). At the beginning of the experiment, members of the group are made aware that they possess unique information that the entire group does not, in addition to the shared knowledge that the group does possess. Participants are, however, unaware that the most optimal decision can only be made if all information is pooled. The group decision outcome and amount of information pooling between group members is measured and investigated. The results of Hidden Profile experiments reveal that unshared information is mentioned significantly less frequently between members, and rarely used to reach a decision (Hayek et al., 2015; Lu et al., 2012).

Stasser and Titus (1985) conducted the most well-known Hidden Profile experiment. The basis of this experiment was to challenge the notion that groups make more informed decisions than individuals. In their experiment, teams of four university students were asked to decide on the best fit of three candidates for student body president. Each participant possessed unique information on each of the three candidates that no other participants had, in addition to equally distributed information. It was only by combining information that the group would be able to determine that candidate A was the best choice. First, participants were asked to rate the candidates before group discussion. Then, after group discussion, the group was asked to disclose who the best candidate would be. The results of their experiment showed that a higher proportion of groups, compared to individuals, selected candidate B as the best choice. It was also found that the support for the best candidate, candidate A, did not increase after discussion. Stasser and Titus concluded that normative pressures of social interaction, rather than the combination of information, influences groups more. Subsequent to this experiment, Stasser (1988) termed this type of experiment "Hidden Profile" because of the hidden nature of the information. Hidden Profile experiments then became known to be a type of experiment where a superior decision alternative exists, but the superiority of the decision can only be revealed once each individual in the group discloses their unique portion of information.

Hidden Profile research tested how groups process information, and accounted for the quality of decisions that they make compared to individuals. However, the underlying assumptions Hidden Profile experiments rely on cannot be generalized to real-world groups decision making scenarios. In a systematic review on Hidden Profile experiments, Wittenbaum et al. (2004) argue that there are three main assumptions that the experiments are based on.

The first assumption is that groups are presumed to be cooperative. In Stasser's (1992) experiments, there lies the assumption that all group members are working cooperatively towards a shared goal of obtaining the most optimal decision. In the experimental paradigm, the incentive structure is symmetrical between all members: they are each told they must discuss the information and decision alternatives to reach a consensus. But, there may be other unknown incentives acting on the group which can affect their decision. For example, a group member may be motivated to get the rest of the group to adopt their own personal decision preference. In other real-world scenarios, such as in a managerial setting, groups may be affected by other motives and incentives. For example, there may be asymmetrical incentives acting on the group, such as individual rewards if the group makes a good decision, or an individual reward if a group makes a specific decision (such as hiring a particular candidate for a job, who may be a personal friend or have similar interests).

The second assumption of Hidden Profile experiments is that groups are presumed to be unbiased. Groups members are assumed to be motivated to communicate all information that they can recall, and to not show preferential learning toward specific information. In real-world settings, such as typical organizational settings, groups are strategic about which information they share, and how they communicate it. An individual might communicate a negative piece of information in a positive light because they are biased towards their own individual incentives. For example, when hiring a job candidate, a group member might reword negative information so that the candidate appears better, or they might withhold the information all together.

The third assumption of Hidden Profile experiments is that groups are believed to be communicating information in an objective manner during their discussion. This type of information communication assumes that unshared information is more important than shared information. This assumption was made by Stasser, who hypothesized that experts possess uniquely high information quality, which might not always be accessible to groups. However, experts may have biased information which might not always sway the group towards the correct consensus. Additionally, unshared information in real-world settings is not always more critical to achieving the optimal decision. Wittenbaum et al. (2004) also note that if the group values social cohesion goals more than the outcome of their decision, then the communication of shared information appeases their social goal and fosters interpersonal closeness.

It is evident that the underlying assumptions of Hidden Profile experiments make them difficult to be generalized the real world settings. Although Stasser and colleagues attempted to gain an understanding of how groups make decisions when information is distributed equally, they failed to account for several facts that could be acting on the group. Manipulating both social and cognitive factors, such as how an expert might affect a group or how groups make decisions when each individual has a different incentive, should be studied as well.

1.3 Complex Problem Solving

In the previous section, the different approaches to problem solving research that have been used both in the past literature and the current literature were discussed. In the Gestalt and Information Processing approaches, individual problem solving experiments were examined. These experiments involved investigating the psychological properties of a problem model, and how humans process problems (i.e. move from the initial state to the goal state). Both of these types of approaches and experiments were conducted on logical problems. In SDS and Hidden Profile approaches, group problem solving experiments were examined. These approaches used problems that involved selecting the best alternative from a set of possible outcomes. For example in typical SDS experiments, groups must choose whether or not a suspect is innocent or guilty. In typical Hidden Profile experiments, groups must choose the best of a set of alternatives to fulfill a job role. In these approaches, the problems are used to explore how groups make decisions. The literature is lacking research on groups, who are either given asymmetrical information or composed of heterogenous groups (based on SDS and Hidden Profile research) that are put in complex problem solving situations (similar to those of Gestalt and Information Processing research). But, there remains a lack of consensus on what a complex problem solving situation is, and how to create an experimental protocol that can encompass the features of complex problems, be manipulated to test multiple facets, and also include real-world like aspects.

In fields such as engineering, science, and organizational settings, researchers have determined that most real-world problem solving occurs in groups (Dunbar, 1998). In groups, there may be more representations of the problem space, and therefore, more alternate ways to reach the solution may become present. Groups also introduce social factors, where one individual can heavily influence the entire group, or contribute unique information that the other members may not have known. Group members can also split up the work more easily, and reasoning can be distributed among group members (Dama & Dunbar, 1996). When defining complex or difficult problems in the context of groups, it is important to mention cognitive and social mechanisms.

In research by French and Funke (1995), and Quesada et al. (2005), complex problems have been thought to contain three main features: being dynamic, time-dependent, and complex. Complex problems are suggested to be dynamic because the early actions of problem solvers can determine the subsequent decisions that must be made by the solvers. Similar to the Tower of Hanoi problem, as one progresses through the problem more moves become apparent, and therefore more of the problem space can be seen. Secondly, complex problems are time dependent because over time, features of complex problems can change independently and/or dependently of the solver's actions. Lastly, complex problems are complex because the problem's features can act on one another, and are not always related to each other on a one-to-one basis.

The characteristics of complexity in complex problems can be further broken down to reveal a more intimate look at the meaning of complex problem solving. Hagemann & Kluge, 2017, characterize complexity by the presence of interconnectedness and interactivity of the problem's features within the structure of the problem, and the existence of non-transparency and multiple and/or conflicting goals, and/or sub-goals. Complexity is also defined as the need to reduce barriers and constraints between the start state of the problem and the intended end state, with the requirement of cognitive activities and behaviour. These barriers and constraints are further characterized as being dynamic themselves, as they can either appear later within a problem, have an effect on other barriers and constraints, or be partially transparent throughout the entirety of the problem.

In an article reviewing the emergence of the complex problem solving field, Funke, 2010**,** states that complex problem solving involves a multitude of factors such as complexity, connectivity, dynamic, intransparent, and a coordinated situation. Funke explains that the number of elements relevant to a complex problem solution are large (complex), highly interconnected (connected), dynamically change over time (dynamic), the structure and dynamics are not always disclosed (non-transparent), and the problem solver is confronted with numerous goal facets that must be coordinated (polytelic). This definition stems from previous research done on complex situations in computer-simulated microworlds (Brehmer and Dorner, 1993), constructed artificial systems that allow for variations of difficulty (Funke, 2001), and also empirical studies done on naturalistic decision-making (Klein, 2008).

A typical artificial system group complex problem study (Hagemann & Kluge, 2017) involved teams completing a microworld C3Fire simulation. In this simulation, teams had interdependent tasks such as extinguishing forest fires and protecting houses. Their dynamic decision making was measured to investigate factors that influence action processes. The authors found that the collective orientation of team members, or in other words the team's ability to collectively pool their actions to reach their goal, had a positive influence on team coordination and performance.

Funke (2010) notes that these studies either lack the complexity that accompanies real-world complex problems, or lack the ability to experimentally manipulate how certain factors might affect the complexity of the problem. For example, in the computer-simulated experimental problems, these tasks lack the dynamics of most real world problems, and look into the decision making outcomes produced by the team, rather than how teams are solving the problem. Naturalistic decision making, on the other hand, involves reflecting on previous decisions that were made in complex situations. Typical work on naturalistic decision making involves interviewing firefighters after they put out a fire, or interviewing a surgeon after they decided what to do with a patient (Quesada et al., 2005). In these types of protocols, the decision has already been made, and experimenters are unable to manipulate how the problem is solved to reveal the underlying factors of group problem solving.

Overall, it is important to study complex problems in groups due to the lacking information and research on the outcomes of group complex problem solving. Complex problem solving research should involve aspects of real world scenarios, but should also be put into an experimental protocol that can be manipulated in order to determine the facts that affect efficient complex problem solving. Unfortunately, it is difficult to generalize from this research on complex problem solving to real-world problem solving, because studies have mostly been done on individuals, or within computer simulated words. Although researchers have not reached a consensus on a working definition for complex problem solving, or how groups solve complex problems, researchers have proposed different models on how difficult problems can be solved.

1.4 Incentives

The problem solving literature lacks research that investigates how groups solve problems under different incentives. Lewin (1936) stated that there are forces which act upon an individual which influence the dynamics of problem solving. While solving for a problem, the individual can be positively attracted towards the solution region, leading them towards it. This most commonly occurred when an individual has an incentive, or motivation, to reach the solution region. But, the problem can be perceived differently by the individual at every stage of the problem space due to the incentives acting on the individual. Groups are equally incentivized or motivated to reach the solution region when solving a problem. However, there may be a difference in the forces acting on each of the individuals within the group. Sometimes groups may be heterogenous and be composed of individuals with different or conflicting incentives. Other times groups may be given an incentive as a whole. Currently, there is a lack of research that exists which addresses the psychological components of group problem solving, including heterogenous group problem solving.

Previous research on groups given different incentives has mostly focused the outcomes of group performance and decision making quality. In a study by Shirani et al., 1998, the role of incentives was investigated on groups who were asked to select the correct alternative on math and English questions. Groups were either given an individual incentive or a group incentive, and were measured on task performance, the number of ideas generated by the groups, and process satisfaction. The authors found that group performance, participation, and satisfaction were higher when group based incentives were present compared to individual based incentives. Although the task involved logical problem solving, it lacked the qualities and characteristics of a complex problem. Barnes et al., 2011, explored the effects of mixed and group incentives on groups who were given a vehicle driving computer simulation. Each participant controlled one of four vehicles with difficult capabilities and were tested on accuracy, speed, backing up behaviour and overall team performance. The authors found that groups who were given the mixed incentive performed better and more quickly than groups who were given the group incentive. However, they also found that mixed incentive groups were less accurate, and completed more of their own individual task work. Moser and Wodzicki (2007) examined the effects of incentives on attitudes towards cooperation and information sharing. Students groups were read hypothetical scenarios that described a group paper writing and presentation task, where grades were based on either individual, mixed or group performance, and then asked to complete a survey. Students given the group based incentive scenario were found to be more willing to share information, assist other group members, had stronger responses to the poor work quality of other group members, and had less withdrawal in response to the perceived lack of commitment of the other group members. Moser and Wodzicki (2007) note, however, that evidence for incentive effects on group cooperation and information sharing behavior is inconclusive, because it is methodologically difficult to distinguish effects due to incentives from those due to structural properties of the group task, such as task interdependence. Lazear and Shaw (2007) found that the use of monetary incentives over other forms of incentives can bring about more difficulties in group settings, as group incentives can lead to free riding.

It is important to discuss that although experimental work has been done on groups with varying incentives, the tasks used in these experiments are not truly complex or difficult problems, but rather logical tasks. These type of tasks do not require incremental searches within a problem space, there is little risk of encountering barriers or needing to detour, and conceptual restructuring is not required to perform the task. The existing research has yet to study situations where individual and group goals may conflict. In these types of situations, individuals in the group may not be aware of the solution path, and must work together to solve the problem by cooperating, pooling information, and integrating resources and ideas. Riedl and Wooley (2016) also note that it is important to avoid conflicts in group settings, specifically between individual goals and group goals, otherwise group goals are likely to be undermined. Reward interdependence, or in other words the reliance on others within the group to receive a reward, can only enhance group performance if it is accompanied by a highly cooperative team, and reward interdependence alone does not assure a cooperative team.

From previous work by Chen (2010), it is known that the largest effect sizes between groups given different incentives are present the more complex a problem is. For cognitive and social factors to interact and influence each other in a group, the group must be challenged and given the opportunity to use these factors while problem solving. The present study is based on Chen's (2010) experimental work, which is built upon a methodology created by Adejumo et al. (2008). Chen's (2010) study, which investigated the performance of groups given different incentives solve problems of various complexity, will be discussed in the following section.

1.5 The Previous Study

The present study investigates the effects of incentives on a group's problem solving processes. This was done by analyzing data and discussions of groups from a previous protocol by Duimering and his student, Chen (Chen, 2010). In this experiment, they tested the performance of groups solving problems in varying incentive conditions. In the current study, the underlying cognitive and social processes of these groups were analyzed in order to determine if differences emerged due to the incentives.

Duimering and his student Adejumo (Adejumo et al., 2008) developed a methodology that integrates both Gestalt approaches and information processing approaches to group problem solving. In this complex problem experiment, groups must incrementally search a problem space, in addition to cognitively restructuring the problem, in order to successfully solve it. In Chen's

(2010) adopted protocol, she used this methodology to test groups who were given different incentive types: a group incentive, a mixed incentive and an individual incentive. These conditions were tested on groups who solved problems of increasing complexity in order to determine if incentives affect group performances. The data from these experiments were used in the current study to investigate whether there were any effects of incentives on the social and cognitive processes of the groups. The experiment conducted by Chen, 2010, will be described in further detail in this section.

1.5.2 Overview of the Card Categorization Experiment

In the experiment, participants were seated at a round table of 1.5m diameter. Participants were assigned letters (A, B, C, D) so that they could identify each other in questionnaires given at the end of the experimental conditions. Participants were each given four cards, with two pictorial items on each card. In the first training condition, participants were able to see the surface of the table and each other's cards. However, for the remaining conditions, a 30cm high T-barrier was placed so that the participants could no longer look at each other's cards (**Figure 3**). This ensured that each group would need to collaborate, as no single individual possessed complete information of the entire problem.

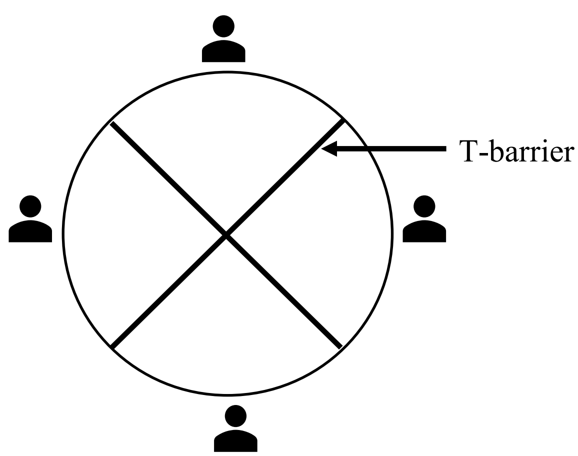

Figure 3. Overhead view of the experimental setup.

Participants, who each began the experiment with four cards, were tasked with achieving four items belonging to the same category. Participants were only able to communicate with each other verbally, and were allowed to exchange cards one at a time. Groups were instructed that they could only hold a maximum of five cards at a time, and must have a minimum of three cards. This prevented having one person be in possession of most of the information of the problem. Each group was given a time limit of approximately 15 minutes.

In Chen's 2010 study, three problem structure conditions were tested: (a) sort, (b) detour, and (c) restructuring and detour. Only the last problem structure (c) was used for analysis in the current study, as this problem was the most complex, and showed the largest differences in performance across the different incentive groups. Chen's (2010) study also included a mixed incentive condition, where groups were given half of the incentive for achieving a solution individually, and the other half for each of the group members achieving a solution. Only individual and group incentive conditions are used to detect the differences between group behaviour and problem solving processes in the current study.

1.5.3 Stimulus Set

The restructuring and detour condition added two additional dimensions into the existing problem structure. Not only did participants have to acquire four items belonging to one category, they also had to cognitively restructure the categories themselves, and they had to avoid blind alleys and make detours if they were stuck. Restructuring was implemented in this condition by having category solutions be comprised of three similarly related items, and one different item. This would force participants to define sets more abstractly in order to make them slightly different item fit in. For example, in **Figure 4**, cards 1, 2, 3 and 4 each belong to the category of alphanumerics. Upon the first glance, it would be easier to categorize cards 1, 2 and

3 together because they each contain a number. Participants would initially see the letter D on card 4 as unrelated. Eventually, cognitive restructuring is necessary in order for participants to change their initial category predictions of numbers into a super-ordinate level category of alphanumerics.

Detours were implemented by including two categories that acted as false sets. If false sets were collected by participants, they would act as blind alleys that would prevent the group as a whole from each obtaining a solution. Detours significantly increased the problem's complexity as participants who collected the false categories must give up their own seemingly correct category. These participants had to move away from a direction that subjectively appears correct for the benefit of the other participants. Recognizing that the false sets are blind alleys also acts as a restructuring task as participants must reformat the way in which they perceive the possible solution sets that they were initially aiming to collect.

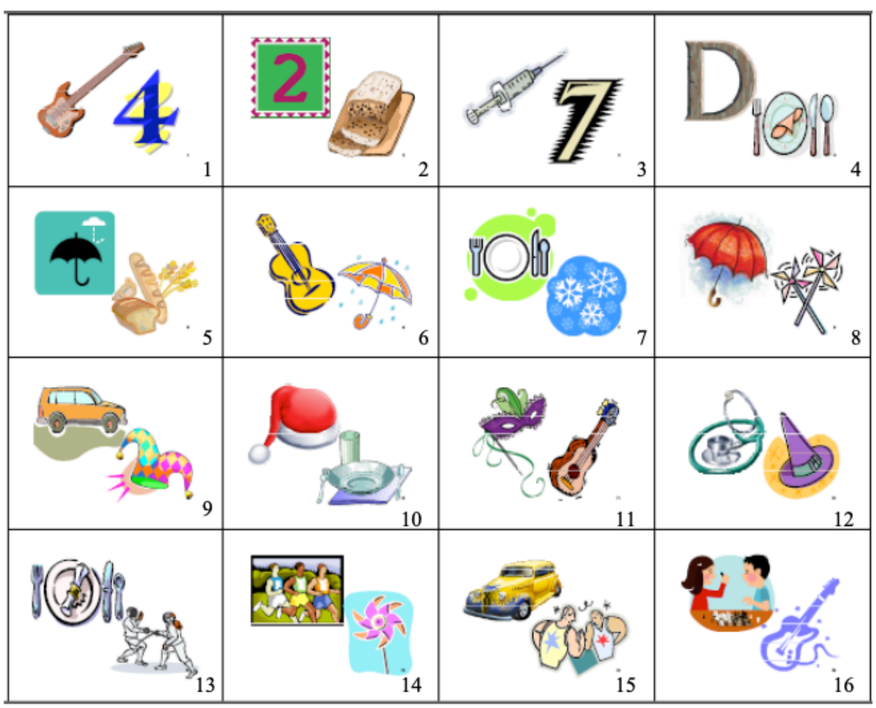

Figure 4. One of three possible stimulus sets for the restructuring and detour condition.

It should also be noted that false sets were comprised of four equally similar items, rather than having three similar items and one different item. This made the false sets more appealing to collect. In **Figure 4**, the two false sets are guitars (comprised of cards 1, 6, 11 and 16) and dinner sets (comprised of cards 4, 7, 10 and 13). The correct solutions for **Figure 4** each involve these cards, but the opposite picture on the card is used. These solutions are alphanumerics (cards 1, 2, 3 and 4), weather (cards 5, 6, 7 and 8), costumes (cards 9, 10, 11 and 12), and sports (cards 13, 14, 15 and 16).

The stimulus set for the restructuring and detour condition was comprised of three different card sets. Each group would only solve one of the three possible sets. This was done to ensure that groups would not encounter similar items between conditions. Within the restructuring and detour condition, participant A always started with cards 3, 8, 11 and 16, participant B started with cards 1, 5, 9 and 13, participant C started with cards 4, 7, 12 and 15, and participant D started with cards 2, 6, 10 and 14. In this distribution, participants A and C received two cards from each of the false detour sets. This was done to entice participants to attempt to collect the false sets, and fall into the blind alleys.

The methodology that Chen (2010) used is unique because it allows researchers to gain insight into the processes behind how groups solve complex problems, especially when there could be competing interests and goals. Groups were required to communicate verbally, and collaborated to make moves towards the solution. Because collaboration was required, groups had to come to an agreement on what they thought the overall solution would be. They also had to coordinate to ensure that each of the individual member’s sub goals did not overlap with one another. Although in the individual incentive condition the groups were heterogeneous in nature, the aspect of collaboration created an additional dimension to the problem. Both the heterogenous (individual incentive) and homogeneous (group incentive) groups mimic most real-world problems, where groups of people must work together to explore a problem space, and sometimes move "backwards" and restructure their perception of the problem in order to achieve a solution. This research and its findings move the problem solving research field forward by investigating what is occurring both cognitively and socially during group problem solving.

1.5.4 Summary of Chen (2010) Results

Multiple types of analysis were done by Chen (2010) to investigate the effects of incentive type on the performance of groups. It was predicted that individual incentive groups would take longer to solve the problem, require more moves, and get stuck in blind alleys more often and for longer times. The results showed that all group conditions were able to solve the problems. However, the individual incentive groups had quicker solution times, required fewer moves, and got stuck in fewer blind alleys. An overview of these results can be seen in **Figure 5**.

One of the main types of measures that Chen (2010) used was the Line Index of Balance (LIB). The Line Index of Balance measures the degree of imbalance in an s-graph adapted from structural balance theory (Cartwright & Harary, 1956; Heider, 1946). This was quantified by counting the frequency of sign negations between lines on the graph. This type of measurement is most commonly used when quantifying a search behaviour in a social network. In this experiment, Chen (2010) used LIB as a means of tracking the search behaviour of the participants, to investigate patterns of card exchange behaviours of participants as they moved from the initial problem state to the solution. LIB was calculated in two ways: subjective path reversals and subjective-objective inequalities. LIB's show the groups subjective understanding of the problem structure, and how far it deviates from the objective structure. An overview of these results can be seen in **Figure 6**.

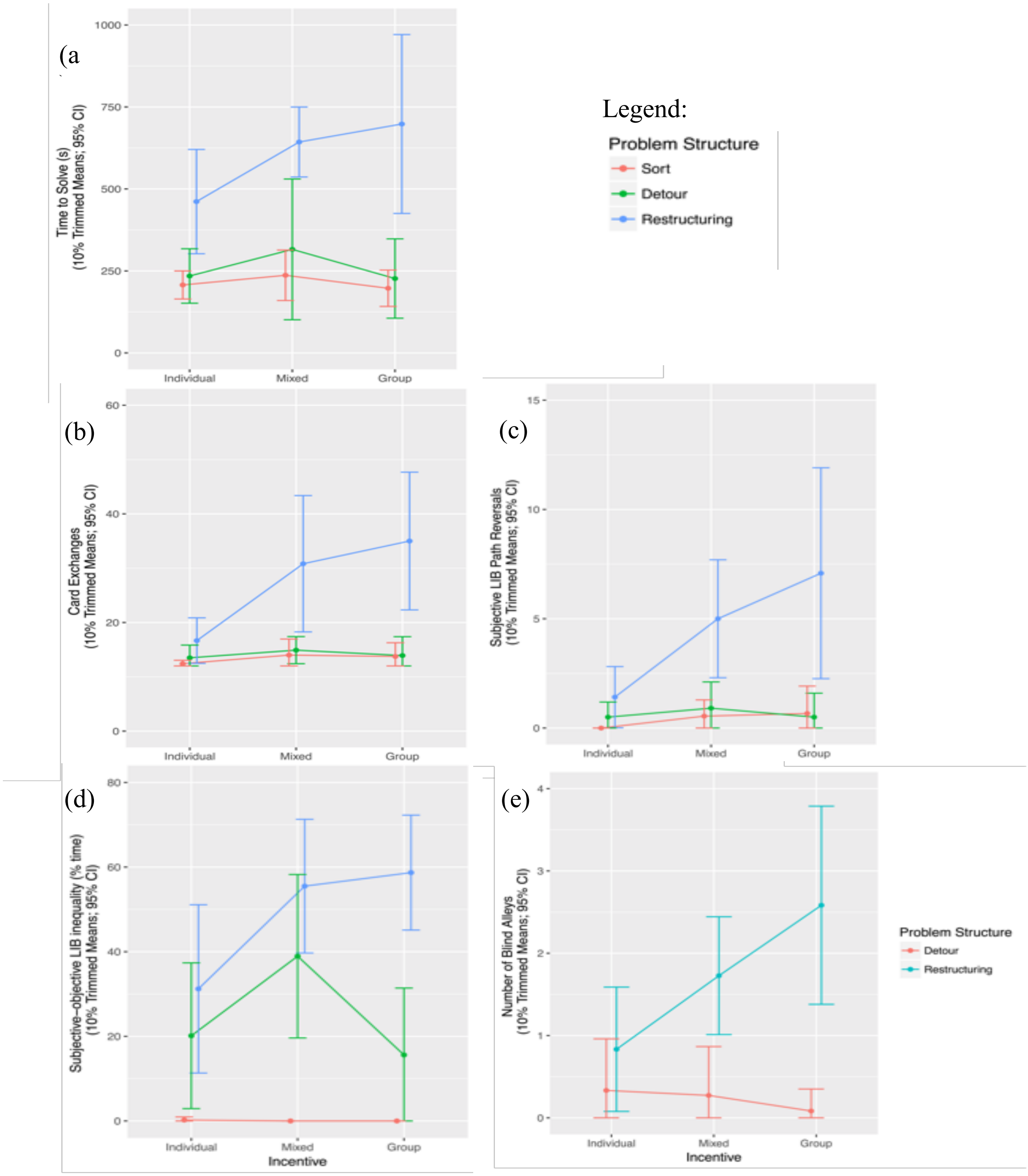

Figure 5. (a) Time to solve, (b) Number of card exchanges, (c) Subjective LIB path reversals, (d) Subjective-objective LIB inequality, and (e) Number of blind alleys by incentive types.

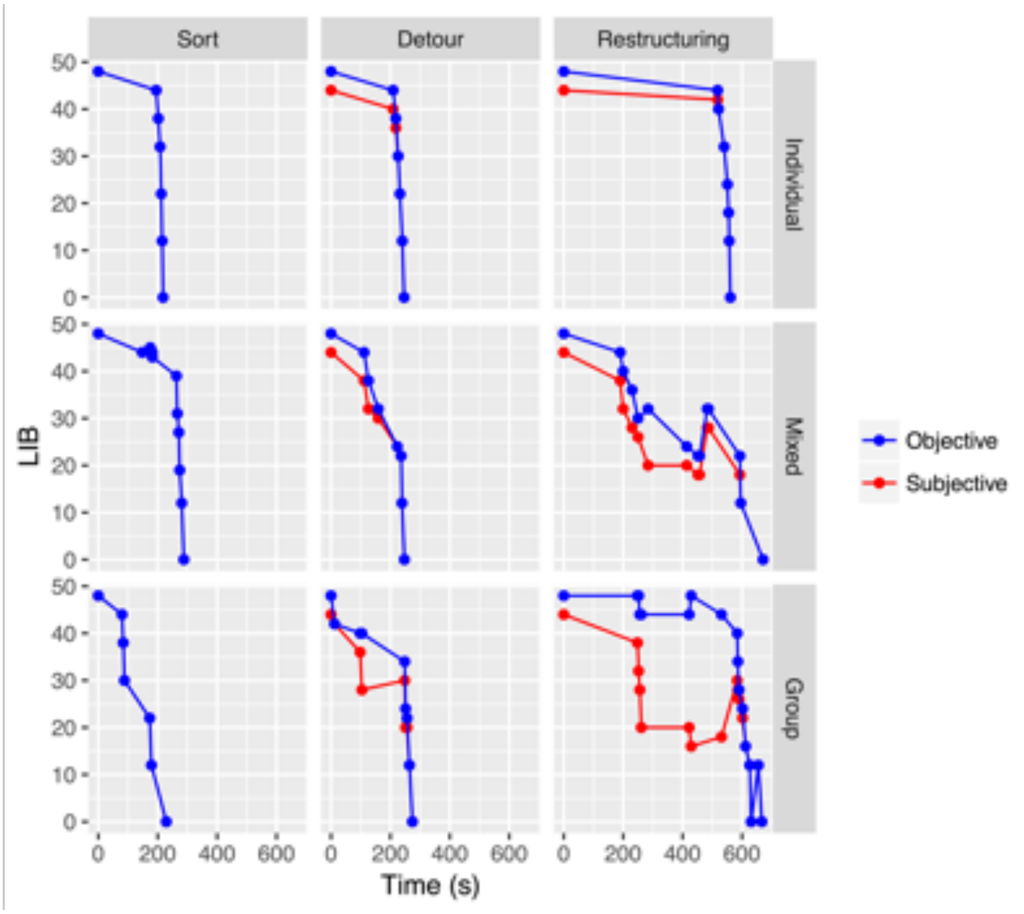

Figure 6. LIB trajectories for typical problem solving sessions, by incentive structure.

The largest effect sizes were seen in the restructuring and detour conditions, which were the most complex type of problem, as explained in the previous card stimulus section. The reason this condition was chosen for the current study is due to these large differences in results. The largest effect sizes were also seen between individual incentive groups and group incentive groups, which was why mixed incentives was not investigated in the current study.

1.6 Literature Overview

In this Chapter, previous literature on group problem solving was discussed. The various approaches to problem solving were examined. The Gestalt approach provides a model for how individuals represent a problem, and emphasizes the importance of perception. Only when an individual accurately perceives a problem, can they begin to solve the problem. This was studied by investigating insight problems, where the problem solver would restructure their perception of the problem resulting in an "aha!" moment, allowing them to visualize the goal state.

Information Processing Theory, developed by Newell and Simon, was another important approach taken by researchers in the problem solving field. The theory has moved the field forward by outlining how a problem can be broken down into its components. Firstly is the initial state, then the intermediate state, and finally the goal state. Problem solvers must navigate through these states by searching through the problem space, which may have barriers and borders. Aspects such as memory and information sharing can affect the way problem solvers navigate through the problem space. Both Gestalt and Information Processing Theory looked at how individuals solve difficult problems, but lacked investigations on how groups approach similar problems.

Then, SDS and Hidden Profile approaches were discussed, which places groups in experiments and measures their performance. SDS proposes a model for group decision making by suggesting that groups reach a decision through the collective combination of individual solution preferences until a solution consensus is reached. SDS has found that individuals within a group can influence one another, and that reaching a consensus is a multi-staged negotiation between individuals. In Hidden profile experiments, individuals within a group are each given unique information, as well as shared information, and the amount of information that is discussed and the performance of the group is observed. Hidden Profile experiments have found that groups discuss shared information more, which leads them to select the incorrect decision. The effect sizes of both SDS and Hidden Profile experiments are measured in terms of the quality or correctness of the output, but little is known about the process of the groups' discussion, or in other words, how the group arrived at their decision and how they cognitively and socially process and interact with the information given to them.

Complex problem solving was also discussed, specifically in terms of the lack of consensus on a definition for complex problems. Both SDS and Hidden Profile experiments are prominent in the problem solving literature, yet the tasks in these types of experiments do not constitute a complex problem. It is known, however, from Chen's (2010) work that the largest effect sizes between groups are seen in the most complex problem condition. Some researchers have suggested that a complex problem is a problem that is dynamic, time-dependent and complex. The complexity of a complex problem can be further analyzed by the presence of interconnectedness and interactivity of the problems features and problem structures, the existence of non-transparency and multiple conflicting goals and/or subgoal, and the need to reduce barriers and constraints within the problem (which can be dynamic themselves). Research on complex problems is difficult due to the challenge of creating an experimental protocol that can encompass these features, be manipulated to test multiple factors, but also include real-world like aspects. This can perhaps account for the lack of research on groups solving complex problems.

Previous research on groups that were given different incentives was also discussed. In the literature, previous studies include those on groups given group based incentives and individual based incentives while completing math and English questions, computer simulated experiments, and hypothetical scenarios. Aspects such as group performance, participation, and group satisfaction were measured. Although this research has found that groups perform better and have higher group satisfaction under group based incentives, much is still unknown about how groups that are given different incentives solve complex problems.

Lastly, the previous study which this work is based on, Chen's (2010) experiment, was outlined. In this experiment, groups given different incentive structures were asked to complete problems of varying difficulties. Group performance was measured and the individual incentive groups were found to perform better (i.e. make fewer mistakes) compared to the individual incentive groups. Although Chen's (2010) experiment involved placing groups in complex problem solving situations, little was uncovered on how, or why, the groups behaved differently. The largest effect sizes between group incentive types were found in the most complex problem type condition, highlighting the importance of studying groups solving complex problems. But, it was still unknown how groups that are given different incentive types process a problem. In the current study, the data taken from Chen's (2010) experiment was analyzed to identify the psychological properties of groups problem solving processes and paths. The study included an experimental protocol that utilizes aspects from both the Gestalt approach (restructuring and detours) and the Information Processing approach (incremental searching) while also incorporating what is known from SDS and Hidden Profile research. This study is important as it fills in some of the gaps of knowledge in the problem solving research field, and discusses how future work can contribute to filling these gaps.

Chapter 2: Methodology

The present study investigates the different processes that groups use to achieve a solution when faced with either group or individual incentives. The data used in this research were obtained from Chen's 2010 study of the effects of problem structure and individual versus group incentives on group problem solving behaviour and performance. In Chen's study, groups were tested on three card categorization experimental tasks, and were randomly assigned to receive either individual, mixed, or group incentives. The three task conditions increased with problem structure complexity, and the largest incentive effects on behaviour and performance were observed in the most complex problem solving task, restructuring and detour.

2.1 Participants

In 2010, 168 students from MSCI 311 from the University of Waterloo, were tested by Lin Chen. Participants were arranged into four person groups, and were given either an individual incentive, mixed incentive or group incentive. For the data used in the present study, the experimental groups that were investigated consisted of 112 participants (14 individual incentive groups and 14 group incentive groups). The incentives were an extra 3% bonus course credit. In the individual incentive condition, extra credit was given to a participant if they alone successfully solved the problem. Participants were told that they would achieve the extra course credit regardless of how other group members performed. In the group incentive condition, the group as a whole received extra credit only if each of the four individuals successfully solved the problem. All experiments took place in the Uncertainty Lab in the Management Sciences department at the University of Waterloo. Each group experiment was recorded by four separate cameras, and two microphones. The cameras recorded from different angles: one from the top of the table where the experiment took place, and three from different corners of the room so that each participant could be seen. All participants were informed that they would be recorded prior to the experiment.

2.2 Protocol

To investigate the effects of incentives on group problem solving processes and paths, several measures and test were put into place. First, group's problem solving behaviours were analyzed through a thematic coding scheme. The first four experimental groups were used as a "trial" for the thematic codes. From these trial videos, major concepts and themes were observed. The hypothesis and results of the thematic coding scheme can be found in **Chapter 3**. After engaging with the evidence from the thematic codes, additional quantitative tests that measured some of the themes from the thematic coding scheme were developed. These quantitative tests, each relating to one of the thematic code themes, can be found in **Chapter 4**. To further investigate how groups process problems, and the paths they take, an additional solution path test was created. In this test, category labels were identified sequentially from each group, and scored as correct or incorrect. The results were then graphed, and the directionality of how groups reached the solution was measured. Combined with the thematic coding scheme, these results allowed for a deeper understanding of the problem solving processes and the underlying cognitive and social mechanisms of problem solving groups. While testing the solution paths, the evidence was also organized based on performance. Groups were ranked according to the number of times they get stuck in blind alleys, the number of card exchanges they used to solve the problem, and the time it took them to solve the problem. These results are reported in **Chapter 4**. Each aspect of the protocol will be described in greater detail below.

2.2.1 Thematic Coding Protocol

The videos of each experiment captured all conditions, including the two initial training tasks in which participants learned the problem task. The videos used for this current research were trimmed to only include the restructuring and detour condition, and then transcribed. The first four videos of experimental footage were used to develop a thematic coding protocol inductively. Two of these videos were of groups who were assigned to the individual incentive, and two were of groups assigned to the group incentive. While watching these four videos, the main topics and topics pertaining to how each of the groups solved the problem were noted. These topics were reviewed to identify themes that were repeated throughout each of the videos. These themes were then broken down into codes which could be detected in the videos. Quotations from specific examples that illustrated each code were noted to be able to determine a specific definition for when and how each code would apply to a certain scenario. Predictions were then made about which codes would have a higher frequency depending on the type of incentive group. The remaining twenty-four were then coded deductively using the coded themes derived from the previous videos. Twelve of these were of groups assigned to the individual incentive condition, and the remaining twelve were assigned to the group incentive condition. Separating the first four videos from the remaining twenty-four allowed for testing differences between the codes. These codes were then counted for each of the twenty-four videos, and then statistically analyzed to reveal if there were any significant differences between incentive groups.

2.2.2 Solution Path Testing Protocol

Further analysis was done on the category labels, or words, that groups used to refer to the cards while solving the problem, to investigate properties of the paths that groups followed to reach a solution (i.e., if they began on the right path, if they were stuck in a blind alley, how did they get out of the blind alley, etc.). This was done by coding the categories to which groups referred, as either correct or incorrect, depending on whether or not the category appeared in the objectively correct solution. Groups might have not used the exact category labels that the solution required, but may have still been correct as per my knowledge as the researcher (e.g. using the category label "house items" instead of "furniture"). By investigating these labels, this provided further insight into the differences in cognitive processes of the two condition types. For example, groups using incorrect category labels at the beginning of a transcript but quickly switching to correct labels might show us that a group is exploring less, but perhaps performing better, than a group which uses incorrect category labels throughout the transcript.

Category labels were assigned numerical values: 0 for incorrect and 1 for correct. These numbers were then averaged by groups of 10, and graphed. Averaging by 10 allowed for a moving average, which gave a representation of how the group was progressing over time. The closer the group was to 10, the closer they were to referring to, or paying attention to, the right category topics. This was an indirect way of quantifying the group's search behaviour within the problem space. Since the problem involves placing items into topics and categories, these numbers give an indication of the extent to which groups search in the region of the solution. Further details and examples can be found in **Chapter 4.**

Moving averages were graphed to visualize the direction in which the group was moving (either towards, or away from the solution). An example of this graph can be seen in **Figure 7.**

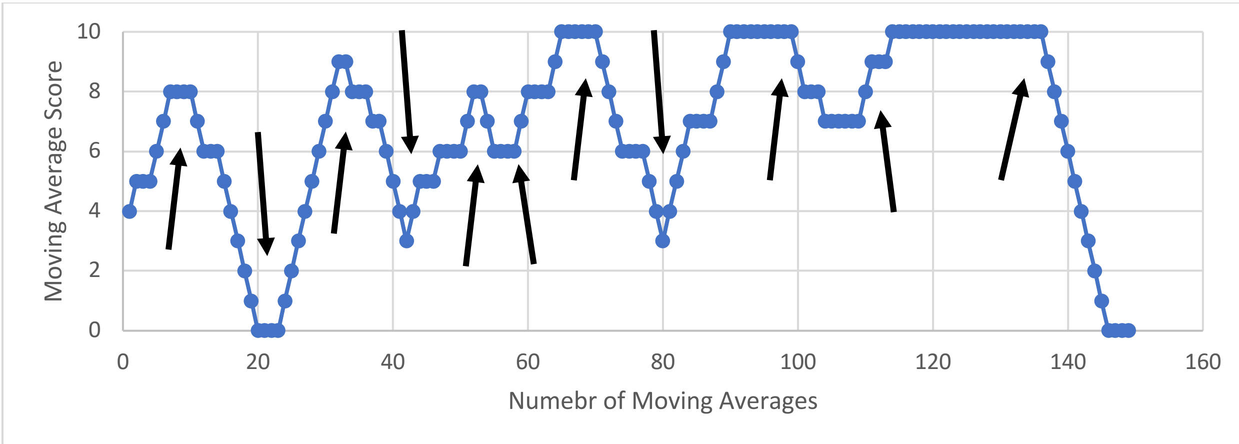

Figure 7. Example of a graph indicating the path a group took to achieve a solution.

To compare differences in behaviour between groups, the number of times a group changed in direction (as indicated by the arrows in **Figure 7**) was counted. This was ultimately utilized to establish the ways in which groups behave while solving a problem. Groups that had more changes in directions were more likely to be approaching the problem incorrectly or in a randomized pattern, explored more, and be further away from the solution. Groups that had fewer changes in directions could be said to be taking a more direct path towards the solution. There was therefore an indication that groups with more directional changes performed worse. In addition to the analysis done on physical card exchanges, this gave an overall picture into the different ways groups solve problems depending on their given incentive.

The concept for this type of measurement was derived from Chen's (2010) use of LIB's. In Chen's (2010) study, she measured how close groups were to a solution objectively through using card exchanges. Those results indicated how many moves away from the solution each group was at a given time. By using verbal cues, this would give a greater insight into the cognitions of the groups rather than just the physical moves that the group makes. This approach shows a refined view of the specific shared cognition within the problem search space. The groups are unaware of the categories will be in the initial problem state, struggle to identify which categories are correct, and gradually zero in on the correct categories with consistent labels while eliminating incorrect categories.

Chapter 3: Thematic Codes

In this chapter, the thematic codes that were created from the experimental video transcripts will be described. Each of the codes will be discussed alongside the hypotheses and the results comparing differences between individual and group incentive conditions. **Table 1** illustrates each of the codes used, the theme that they illustrate, how they were applied in the transcript, and examples.

Code	**Theme**	**Code Application**	**Examples**
1: Memory	Information Processing	Verbal cues that indicate memory struggle	1. "And what do you have? I keep forgetting" 2. "I wish we could write things down, there's too much"
2a: Awareness of blind alleys	Problem Structure	Comments of the awareness of a blind alley category	1. "…the whisk we can't give all to 1 person because that messes up 2 other people."
2b: Awareness of restructuring	Problem Structure	Comments of the awareness that solutions are made of 3 similar cards, and 1 different card	1. "For all of them, there's one that doesn't sorta fit" "Yeah, I have a D that doesn't go with my numbers" 2. "Maybe it's to trick us. There's an odd one out. I have three hats and a mask"
2c: General awareness of the problem structure	Problem Structure	Comments of the awareness of the problem structure or task structure, such as the understanding that one picture on a participants card might conflict with another category. [1]	1. "My chair is with my coffee so we can't do furniture if you're collecting coffee cups"
3a: Requesting information about card items	Information Sharing	Asking another participant for information about their cards.	1. "What do you have?" 2. "Do you have a loaf of bread?"

[1] Code 2c was used for all statements of general problem structure awareness, and did not include statements of awareness of the blind alleys (2a) or restructuring (2b).

3b: Giving information about card items	Information Sharing	A participant giving information about their own card.	1. "I have a Santa hat" 2. "No, I don't have an egg beater"
4a: "We"	Communication	A participant says "we".	1. "We should collect furniture as a group"
4b: "I"	Communication	A participant says "I".	1. "I'm going to collect egg beaters"
4c: Talking over each other	Communication	Participants are talking over one another	Inability to transcribe what a single individual is saying because others are talking over them.
5a: Willingness to explore	Exploration	A verbal indication that a participant is willing to make a random move or explore.	1. "Do you guys want to try and rearrange them? Like we know now that I have all the vases, so we can always go back to it in a second" 2. "Just give me anything and then we will figure it out" 3. "Let's just try hockey and see what happens from there"
5b: Unwilling to explore	Exploration	A verbal indication that a participant is unwilling to make a random move or explore.	1. "Let's just try to exchange some" "No, just a second. Let's make sure we have the four things first" 2. "Let's try different combinations though" "No, we don't really have time for that"
6: Solution prediction	Solution Path	Participants make a prediction of what a category could or could not be.	1. "We all have sweaters and shirts, clothes could be one" 2. "Ok I think birds would work"
7: Solution movement	Solution Path	Participants are making indications of the moves they will make (i.e. which cards or categories they or others will be collecting). This includes negotiations for collecting certain card categories.	1. "I'll take the birds" 2. "You take bridge, I'll get the exercising"
8: Completed solution	Solution Path	Participants state that they have all four cards	1. "I have four structures" 2. "I have sports equipment"

		to the category they collected.	
9: Uncertainty	Uncertainty	Participants verbally indicate that they are unsure of a category that they collected.	1. "I'm not so sure that my computer group is right"

Table 1. Thematic codes, the themes that they illustrate, how they were used in a transcript, and examples of quotes from where they were used.

The codes listed above in **Table 1** were each developed differently. Some codes were derived deductively by applying patterns from previous theories. For example, information processing (code 1), information sharing (codes 3a and 3b), and uncertainty (code 9) were developed based on Simon's Information Processing theory (1978). Other codes were developed inductively by carefully looking at what is occurring in each of the four trial experimental videos. Problem structure (codes 2a, 2b, and 2c) was mainly induced from Chen (2010) and Adejumo's (2008) previous design of the stimulus. The largest differences were observed in the restructuring and detour condition, and therefore I wanted to investigate this concept further to explore if there was a difference between incentive conditions. Communication (codes 4a, 4b and 4c), exploration (codes 5a and 5b), and solution path (codes 6, 7 and 8) were induced from observing the participants behaviours while solving the problem.

Each of these codes will be described in detail below, in addition to the hypotheses that were made on the differences that may arise between incentive group type, the results of the thematic code testing, and brief discussions of these results. It should be noted that only results pertaining to thematic codes are included in this chapter. Additional analyses were performed pertaining to some of the topics and themes from this chapter. Those results are reported in

Chapter 4, but the concepts and reasoning behind some of these tests are reported throughout their appropriate thematic sections.

3.1 Information Processing: Memory

One of the main components of the cognitive mechanisms a group uses when solving a problem is information processing (Newell & Simon, 1972). In this experimental protocol, there is a minimum amount of information processing that all groups must perform in order to solve the problem. In order to gain insight into the cognitive mechanisms of problem solving groups, it was important to capture information processing in the thematic coding. While creating the thematic codes, I noticed that there were different ways in which groups commonly processed information. The first was through memory, and the second was through the way groups shared information **(see 3.3)**.

In research on human perception, memory has been known to influence the way in which we are able to process information. Through sensory memory, short term memory, and long term memory, humans are able to selectively infer concepts, pay attention to specific items, and categorize things based on their past perceptions (Palmer, 1990). In the experiment, participants are required to process information when they receive new information about the problem. This can occur in two ways: when the participants exchange cards, or when participants discuss which cards they possess. When participants describe the cards that they possess verbally, the other participants are forced to keep these items in their memory, and attempt to create categories from the collective information pool of the group.

To measure the different ways that groups processed information by memory, I implemented a memory code into the thematic coding, but also counted the number of times that participants repeated category label words. The details and results of the frequency of word repetitions are reported in **Chapter 4**. In the thematic coding for memory, the memory code tracked all explicit verbal cues of memory load struggles. This mostly included participants exclaiming phrases such as “I forgot what you had, can you repeat it?”. Examples of transcript quotes are shown in **Table 1**.

3.1.1 Memory Hypothesis

From Chen’s 2010 study, it was found that individual incentive groups make fewer card exchanges than group incentive groups. Assuming that card exchanges is one means of sharing information, this could mean that individual incentive groups would be under increased cognitive load to remember the cards that other participants have, in addition to creating categories from these cards. From previous studies such as Hidden Profile experiments, individuals in groups are less likely to disclose unshared information. Hidden Profile experiments were, however, completed on groups that were not given incentives. There is evidence that groups have a hard time sharing unshared information, but with the addition of incentives, this might have a differential effect. In the current experiment, groups must collaborate and share a minimum amount of information, but we don’t know how much information they would share, and what would occur with these additional factors.

It was hypothesized that individual incentive groups would be less likely to share a category that they have created in their heads due to the risky nature of disclosing their individual strategies or cards. If individuals were to share each of the items in their possession, this could mean that another individual might want to take one of their cards. Individual incentive groups might therefore only report the minimum amount of information they think is necessary.

Since group participants could only process information in one of two ways (either exchanging cards or verbally dictating card items), it was predicted that individual incentive groups would be more likely to dictate cards rather than risk trading cards. It was therefore hypothesized that individual incentive groups will have a higher frequency of memory codes. Individual incentive groups would have to keep more information in their memory, and this could be seen through the increase of word repetitions during discussion, and making noticeable verbal cues of memory struggles during discussion.

3.1.2 Memory Results

The results of the explicit memory code are reported below in **Table 2**. From the 24 videos that were analyzed for an explicit verbal memory code, Code 1, there were only five groups that had this code. Three of those were individual incentive groups, and two of them were group incentive groups. There was no significant difference ($p>0.1$) in the frequency of memory codes between individual incentive groups ($M=0.67$) and group incentive groups ($M=0.25$). Other results on measurements of memory can be found in **Chapter 4**.

	Individual	**Group**
Mean frequency of Code 1	0.67	0.25
SD	1.37	0.62
	T-test	
Degrees of freedom	15	
$P(T \leq t)$ two-tail	0.35	

Table 2. Results of Code 1: Memory.

Although these results indicate no significant differences of the frequency in which Code 1 appears between the groups, 79.16% of the groups did not have Code 1 to begin with. Of all the groups, the code appeared on an average of less than 1 time per group (M=0.67, M=0.25). This data is not strong enough to place through a statistical analysis to give an indication if there is a true difference in memory struggles between group types. Since the measure did not detect a difference, this indicates that the code itself did not work, and the concept of testing memory struggle was unable to be captured in this method.

If groups are not expressing struggles of memory explicitly, it becomes difficult to test how they might be dealing with the load on their memories. However, in **Chapter 4**, I attempted to measure memory in other quantifiable ways, such as testing the amount of times a category label is repeated, and the amount of card exchanges each group makes. If incentive affects the way that groups process information, and therefore the way in which they approach problems, then these measures should show a difference.

3.2 Problem Structure

In Simon's Information Processing theory of human problem solving, he states that a large part of information processing is also searching for the problem structure (1978). In order to solve a problem, one must move through the problem space in order to reach the solution region. To search through the problem space, problem solvers must first understand its dynamics, or in other words, the barriers of the space and it's various regions.

In this experiment, the problem structure consists of two main components: the structure of the task, and the additional effects that incentives impose on the task. The structure of the task is further broken down into its components: exchanging cards to reach four items that make up a category, recognizing and/or detouring around blind alley categories, restructuring the perspective of the problem in order to select the appropriate categories, and other minor aspects such as acknowledging that the 2 items on a card cannot be used for two different categories, and the extra paired items that are used as distractions. The effects that incentives impose on the task changes the problem structure because incentives change the way that the problem is approached.

Having an accurate representation of the problem structure allows problem solvers to be able to initiate problem solving, as per Gestalt theory. Since the current experiment has aspects of restructuring and detours, having an accurate representation of the problem structure is essential to reaching a solution. In order to measure indications of participants' perception of problem structure, thematic coding was analyzed in three different ways: code 2a, code 2b and code 2c. Code 2a was used when there were any explicit indications of participants being aware that there were blind alley categories, which was integral to the task structure of the problem. Code 2b was used when there were explicit indications of participants being aware that restructuring was necessary in order to perceive the correct category solutions (i.e. that there were 3 similar card items and 1 dissimilar item per category). Lastly, code 2c was used when participants made any general comments of their awareness of the problem structure, such as being aware that they could not create two categories from one card. Codes 2a, 2b and 2c were combined to measure the group's overall understanding of the problem structure. If groups have more comments about the problem structure, this might indicate that they are conceptually working out the problem, and trying to mentally represent the structural properties of the problem. If groups are discussing the structure of the problem more, this might suggest that they are more tuned into the structural properties of the problem, allowing them to search through the problem properly. By possessing an accurate mental representation of the problem, groups are able to have a more direct search path to the solution.

3.2.1 Hypotheses of awareness of blind alleys, restructuring, and general awareness

In the individual incentive group condition, groups are faced with a larger risk as they can only attain the reward if they themselves achieve a solution. If an individual falls into a blind alley, a much more attractive category consisting of 4 similar items, they might be less likely to give up this category for the betterment of others. This poses an additional consequence for the other participants who are left with no category solution at all. It was therefore predicted that in the individual incentive condition, groups would be more likely to make more calculated moves based on a better understanding of the problem structure.

From Chen's (2010) experiment, it was found that individual incentive groups fall into blind alleys less often, with fewer card exchanges. In this experiment, I attempt to figure out why this may be, and the underlying mechanisms that they use in order to make "better" moves that directly lead them to the solution. I therefore hypothesized that individual incentive groups avoid falling into blind alley categories due to their better understanding of the problem structure, and would therefore have more 2a, 2b and 2c codes. The task structure, combined with the task environment (the effect of incentives), would lead individual groups to be more in-tuned with the problem structure in order to avoid making risky moves that would place them in jeopardy of not attaining a solution themselves.

3.2.2 Results of problem structure codes

The results of the problem structure codes are reported below in **Table 3**. The three codes, awareness of the blind alley (2a), awareness of restructuring based on dissimilar items in categories (2b), and general awareness of the problem structure (2c), were analyzed in terms of the frequency in which they were coded for in the transcripts. They were also standardized by the total time of each of the experimental videos. For Code 2a, only 1 individual incentive group had this code, while 3 group incentive groups had this code. There was no significant difference ($p>0.1$) between the individual incentive groups ($M=0.083$), and group incentive groups ($M=0.25$). When standardized for time, the results still showed no difference ($p>0.1$) between individual incentive groups ($M=0.0000957$), and group incentive groups ($M=0.00041574$). For Code 2B, 9 individual incentive groups had this code, while 7 group incentive groups had this code. There was no significant difference ($p>0.1$) between the individual incentive groups ($M=2.25$), and group incentive groups ($M=1.583$). When standardized for time, there was still no significant difference ($p>0.1$) between individual incentive groups ($M=0.00435$) and group incentive groups ($M=0.00253$) for Code 2b. For Code 2c, all groups had this code. There was also no significant difference ($p>0.1$) between individual incentive groups ($M=15.41$) and group incentive groups ($M=12.67$). However, when standardized for time, there was a significant difference ($p\leq0.1$) between individual incentive groups ($M=0.0263$), who recognized problem structure more frequently than group incentive groups ($M=0.0169$).

Codes 2a, 2b and 2c were combined together to reveal the groups' overall awareness of the problem structure. This was done because not all groups had codes 2a and 2b, and this gave a generalized picture of the code. The results showed that there was no significant difference ($p>0.1$) between individual incentive groups ($M=17.34$) and group incentive groups ($M=14.5$). However, when standardized for time, there was a significant difference ($p\leq0.05$), as individual incentive groups had a greater number of combined problem structure codes ($M=0.02$) compared to group incentive groups ($M=0.01$).

	Individual	Group
Mean frequency of Code 2A – Blind alley awareness	0.08	0.25
SD	0.029	0.45
	T-Test	
Degrees of freedom	19	
P(T ≤t) two-tail	0.29	
Mean frequency of Code 2A/sec	9.57×10^{-5}	4.15×10^{-4}
SD	3.18×10^{-4}	7.56×10^{-4}
	T-Test	
Degrees of freedom	15	
P(T ≤t) two-tail (per sec)	0.19	
Mean frequency of Code 2B - Restructuring awareness	2.25	1.58
SD	2.17	2.60
	T-Test	
Degrees of freedom	21	
P(T ≤t) two-tail	0.50	
Mean frequency of Code 2B/sec	0.004	0.002
SD	1.75×10^{-3}	3.71×10^{-3}
	T-Test	
Degrees of freedom	19	
P(T ≤t) two-tail (per sec)	0.36	
Mean frequency of Code 2C – General problem structure	15.41	12.67
SD	9.93	8.29
	T-Test	
Degrees of freedom	21	
P(T ≤t) two-tail	0.47	
Mean frequency of Code 2C/sec	0.26	0.017
SD	5.24×10^{-3}	7.61×10^{-3}

	T-Test	
Degrees of freedom P(T ≤t) two-tail (per sec)	15 0.095	
Mean frequency of combined 2A, 2B and 2C codes SD	17.34 9.88	14.5 7.41
	T-Test	
Degrees of freedom P(T ≤t) two-tail	20 0.43	
Mean frequency of combined codes/sec SD	0.02 0.01	0.01 $5.89x10^{-3}$
	T-Test	
Degrees of freedom P(T ≤t) two-tail	14 0.05	

Table 3. Results of code 2a, 2b 2c, and combined: Problem Structure.

Although codes 2a and 2b did not show any significant differences between group incentive types, this could again be due to the lack of results per group. Code 2a only appeared in 4 of the 24 experimental groups, while code 2b only appeared in 16 of the 24 groups. A possible reason why code 2a may not have appeared as frequently may be because it is still possible to solve the problem without ever encountering a blind alley. Individual incentive group participants may have also withheld whether or not they were in a blind alley because the individual who collected 4 similar items, a very appealing category, would not want to lose their solution. However, the results of the combined code (2a, 2b and 2c) indicate that there is a significant difference between the group types. Individual incentive groups made more overall comments about the problem structure, which may indicate that they are paying more attention to the structural properties of the problem, and working out a mental representation of the problem.

If individual incentive groups are able to do this better than group incentive groups, then this might indicate that they would also be able to have a more efficient and direct search path.

It should be noted that in Chen's (2010) experiment, groups were given a questionnaire after completing the problem. In this questionnaire, groups were asked to write down which aspect of the problem that they found most challenging. After reviewing the responses to these questionnaires, it became apparent that some individuals were aware that there were blind alleys, even though they did not disclose this during the experiment. Due to the subjective nature of these responses, and due to the lack of there being an explicit question asking if the participants could identify that there were blind alley categories, I did not add these responses to the current statistics. Below are some direct quotes from the questionnaires that may possibly indicate that participants had understood there was a blind alley:

1. *"The fact that we had 4 guitars that would interfere with the costumes"*
2. *"When we were able to get 2 full sets of 4 while not having the other 2 sets possible"*
3. *"We tried to put the guitar and eating utilities in a group first, but we realized we cannot form the other two groups. So we know that's not the right answer"*

From the questionnaires alone, there were a total of 9 individual incentive participants that indicated blind alleys in their questionnaire responses, and 5 group incentive participants.

Since groups had a large variation in the time it took them to solve the problem (ranging from ~5 minutes to ~25 minutes), codes were standardized to analyze the rate that they appear over time. This would ensure that codes would not appear more frequently just because the group had more time for discussion. This was done to capture the group's true understanding of the problem's structure, and identify if incentives affected their understanding. When Code 2c, which was used when groups explicitly exclaimed that they understood an aspect of the problem's structure, was standardized, the results showed that there was a significant ($p \leq 0.1$) difference between individual incentive groups and group incentive groups. Because these results were not significant when time was not standardized, this suggests that group incentive groups spend more time to recognize the problem structure, in addition to not recognizing the structure as well as individual groups (M=15.41 vs 12.67).

3.3 Information Sharing

The amount of information that we share can affect the amount of information we must process, and therefore ultimately affect our ability to solve problems efficiently. The more information that is known, the larger the cognitive load. In asymmetric problems, similar to Hidden Profile experiments, groups do better when they share more information In a meta-analysis on the effects of information sharing on team performance, Mesmer-Magnus and Dechurch (2009) note that information sharing is an integral process for groups to be able to collectively use the maximum amount of available information resources. In their analysis on 72 independent studies, they found that the more information that is shared among team members, the greater the team's performance and decision satisfaction. The authors note that these results may change based on the task type, performance criteria and the structure of the discussion. They also found that one of the factors that caused a decrease in team information sharing was member heterogeneity.

Changing the way that the problem is approached could mean that one group might begin in a different region of the problem search space compared to other groups. For example, while watching the four experimental trial videos, it seemed as though the different group types adopted different strategies when beginning the problem. Group incentive groups would begin by listing off every item that they had, and would openly share information. In individual incentive groups, individuals would begin more hesitantly and only disclose a few items. In Simon's (1978) terminology, this is an example of how the structure of the task environment determines the possible structures of the problem space. There are differences in the way groups share information, the strategies that they follow, and the way they engage with the problem because of the differences in incentive types. For example, if individual incentive groups are stuck in a blind alley, this scenario, or problem region, becomes more competitive compared to when group incentive groups are stuck. If a group incentive group were to be stuck in a blind alley, they would perceive it to be a collective problem rather than a competitive problem.

While reviewing the first four experimental videos for themes, one noticeable difference between the groups were the way in which participants asked for, or gave, information. Some participants had either clearly shown reservations to give information, and when asked directly about the card items that they had, they would not disclose all items. On the other hand, other participants would begin the experiment by listing all the items that they had, and expected others to as well. To code for this, the information sharing code was created. 3a was used for all accounts of participants asking for information about other's card items, such as "Do you have a chair?" or "What items do you have?". This included asking for a trade (e.g. "Can you give me a chair?"), to ensure that all questions were captured in the coding. The other code, 3b, was used when participants gave information about their own card items. This included phrases such as "I have a chair", or "I don't have a chair". All statements of card information were counted when participants were asking for card trades as well. Similar to the problem structure condition, code frequencies were standardized in the analysis to account for the differences between groups in the time they needed to solve the problem. Since some groups took longer to solve the problem, this might give them more opportunities to ask for or give information.

3.3.1 Hypotheses of sharing versus giving information

In the current experiment, due to the addition of incentives, sharing information poses a risk to participants in the individual incentive groups. The more information that they share about their cards, the greater risk they have for giving up their cards to others who may need them. They may also choose to not disclose which cards they have until they are confident that they possess a solution. Group incentive groups are incentivized to behave in the opposite manner. The more information that they share, the more they can understand about the problem's structure, and the closer they are to solving the problem. I therefore hypothesized that individual incentive groups will have fewer 3b codes than group incentive groups, because they will be more reluctant to give information. Code 3a, which was used when group participants asked for information, was hypothesized to be equal between groups. This was because the problem itself requires information to be shared, and for a certain amount of collaboration to occur, in order to make solution moves and reach the goal state.

3.3.2 Results of sharing versus giving information

The results of the differences in information sharing codes are reported in **Table 4**. This table denotes the analyses done on code 3a, which was used when group participants asked for information, and code 3b, which was used when group participants gave information. The results for code 3a show that there was no significant difference ($p>0.1$) for individual incentive groups ($M=52.42$) compared to group incentive groups ($M=65.58$). When standardized for time, the analysis still showed no significant difference between groups ($p>0.1$). For code 3b, the results show that there was a significant difference ($p\leq0.0.5$) between individual incentive groups ($M=119.34$), who had fewer codes for giving information compared to group incentive groups ($M=284$). When standardized for time, the results still remained significant ($p\leq0.1$).

	Individual	Group
Mean frequency of Code 3a	52.42	65.58
SD	23.11	37.04
	T-Test	
Degrees of freedom	18	
P(T ≤t) two-tail	0.31	
Mean frequency of Code 3a/sec	0.09	0.11
SD	0.05	0.045
	T-Test	
Degrees of freedom	21	
P(T ≤t) two-tail	0.49	
Mean frequency of Code 3b	119.34	284
SD	66.71	120.15
	T-Test	
Degrees of freedom	17	
P(T ≤t) two-tail	0.048	
Mean frequency of Code 3b/sec	0.34	0.46
SD	0.17	0.53
	T-Test	
Degrees of freedom	22	
P(T ≤t) two-tail	0.10	

Table 4. Results of codes 3a and 3b: Information Sharing.

In this experiment, both individual incentive groups and group incentive groups must ask for a minimum amount of information in order to solve the problem. The problem information is distributed equally in the sense that each participant begins with the same amount of information, but it is distributed asymmetrically such that the information held by each participant is unique. The participants must collectively engage in some type of discussion, or make physical card trades, in order to solve the problem either individually or as a group. Code 3a, which was used anytime a participant asks for information, did not show to be different between the two group types. Without subtracting the true "minimum" amount of times that participants must ask for information, there is no way to truly tell if there is a difference between groups. The same can be said for code 3b – all participants must give a minimum amount of information in order for the problem to be solved. However, individual incentive groups gave much less information compared to group incentive groups. The structure of the task allowed for the problem to be solved by giving only a minimal amount of information, but groups engaged in more discussion and revealed more items on their cards.

Chen's (2010) results showed that group incentive groups got stuck in blind alleys more often ($M_{(blind\ alleys)}$=2.67, $Total_{(blind\ alleys)}$=32) and took more time to solve the problem ($M_{(problem\ solving\ time)=}$ = 723.5 seconds) compared to individual incentive groups ($M_{(blind\ alleys)}$=1, $Total_{(blind\ alleys)}$= 12, $M_{(problem\ solving\ time)=}$ 665.41 seconds), indicating that group incentives led to relatively worse performance (**see Chapter 4.3**). If groups performed worse, but they shared more information, this suggests that sharing more information placed the group at a disadvantage. Perhaps this was due to the amount of information that participants were giving each other (some groups incentive groups had 589 3b codes). This amount of information could have been too much for the group members to keep in their memories, which may have lead them to become confused, and take longer to solve the problem.

The results remained significant when standardized for time, which indicates that the results are not due to the differences in time that the groups took in order to complete the problem. If groups took longer, this may have given them more opportunities to ask for and give information, however, values remained relatively similar.

3.4 Communication

In some of the earliest studies on group behavior, researchers have always noticed the increased feeling of cohesiveness when groups and teams work together (Kidwell et al., 1977; Schlenker & Miller, 1977). When including incentives in a group problem solving task, perhaps this would lead to increased feelings of individuality and less group cohesion when solving the problem. Group incentive groups are likely to be willing to work together to solve the problem, while individual incentive groups might experience more conflict and competitiveness.

3.4.1 Communication: "We" vs. "I"

While watching the first four experimental videos and developing themes for the thematic codes, I noticed that some of the groups were communicating with one another differently. It had seemed as though group incentive groups were adopting a more cooperative, language compared to the individual incentive groups. For example members of individual incentive groups appeared to be making more references to their own individual category solutions rather than the group's complete solution. This was especially apparent at the end of the problem solving task, when participants announced that they were finished. In group incentive groups, participants would say "we're done", while in individual incentive groups, participants would say "I'm done". To test the differences in language, I created the codes 4a, which was used whenever groups used the word "we" to reference having a category or solution, and 4b, which was used whenever groups used the word "I" to reference having a category or solution.

When first using these codes, it became difficult to disentangle when to code something that was being referred to as "we" versus "I". When participants would mention which category solutions they had, they might have been using a first person language, but still felt as though they were part of a cooperative group. I therefore decided to only use the code at the end of the experiment, when participants would announce that they were done. However, this also became muddied, as some participants used both an "I" and "we" language when talking to the experimenter. Due to the added subjectivity of interpreting each of the phrases and deciding whether the group was using "we" or "I" in a cooperative, or individualistic manner, I ended up not testing this code. Simply searching for all of the words "we" and "I" that appeared in the transcripts and do a simple comparison test was not feasible, as the same issue was raised again. Some group members had to use the word "I" when referring to the cards that they had in their possession, but still appeared to have communicated in a more cooperative manner overall. We ultimately concluded that there was no objective, or replicable, way to test the language differences between the group types. In future experiments, feelings of group cooperativeness or cohesion could be asked in a post-experimental questionnaire.

Before deciding not to test this code, I hypothesized that individual incentive groups would be more likely to use the word "I" (code 4b) rather than "we" (code 4a) due to the nature of their incentive. Their individual solution path did not have to involve the other group participants, and therefore participants could have chosen to only focus on attaining their own solution.

3.4.2 Communication: talking over one another

Another noticeable communication difference between the group incentive types was the amount of times group participants spoke over each other. This was first noticed while transcribing the videos itself, because when group participants would speak over each other frequently, I was unable to transcribe what they were saying. I had decided to make a note when participants were inaudible due to speaking over one another, which eventually became code 4c. This code was initially a procedural code, but it became apparent that group incentive groups had been speaking over one another much more frequently than individual incentive groups. To test this, I compared code 4c between group incentive types.

3.4.3 Results of talking over one another

The results of code 4c, which was used anytime the transcript was unable to be transcribed due to participants speaking over another, can be seen in **Table 5.** A significant difference ($p \leq 0.1$) was found between individual incentive groups, who had less of the code (M=0) compared to group incentive groups (M=3.34). When standardized for time, the results remained consistent ($p \leq 0.1$). However, it should be noted that none of the individual incentive groups had any 4c codes, while only 6 of the 12 group incentive groups had the code.

	Individual	**Group**
Mean frequency of Code 4c	0	3.34
SD	0	5.89
	T-Test	
Degrees of freedom	11	
P(T ≤t) two-tail	0.07	
Mean frequency of Code 4c/sec	0	0.007
SD	0	0.014
	T-Test	
Degrees of freedom	11	
P(T ≤t) two-tail	0.1	

Table 5. Results of code 4c: Social Communication, talking over one another.

Group incentive groups had noticeably different communication styles compared to individual incentive groups, although each group seemed as though they developed their own unique communication style. Some groups spoke very quickly, while others spent more time thinking and concentration. I implemented code 4c in order to investigate more of what is occurring in these communication style differences. If groups are carefully thinking out their solution paths, then they would be engaging in more information processing and ultimately carefully working out the problem structure. This would intuitively translate into a more concentrated and careful communication style. If group participants are talking over one another, they would not be able to carefully listen for the information that they need. In a group incentive group, this might not be as risky as in an individual incentive group, where participants are trying to attain the cards that they specifically need.

3.5 Exploration

In the present experiment, groups do not have to explore the entire problem space in order to reach a solution. However, groups must share a minimum amount of information with one another to reach a solution. Groups do not have to disclose every item on their card, or explore every pair or category. It is not necessary for groups to explore the whole problem space to understand all aspects of the objective structure. They must only understand enough of the structure to get to the solution, but the additional aspects are not necessary to achieve the solution. However, some groups may choose to spend more time trying to identify every possible category before agreeing on a solution.

Incentive types may affect which groups are more willing to explore the problem search space. Codes 5a and 5b were created in order to capture this concept. Code 5a was used anytime a participant was making explicit comments that they were willing to explore more of the problem space, i.e., make a "random" trade. This included phrases such as "What if we try this out anyway and see what happens?". Code 5b was used anytime a participant indicated that they were not willing to explore the problem space. This included phrases such as “No, let’s stick with what we have now”.

3.5.1 Hypothesis of groups’ willingness to explore

The methodology of this experiment integrates both Gestalt theory, with the inclusion of restructuring, and information processing theory, with the inclusion of an incremental search, which requires the participant to explore a minimum amount of the problem search space in order to achieve a solution. When participants exchange information about the problem, they do not have to disclose every item in their hand to be able to create categories. But, incentives may influence the amount of problem space that groups spend their time searching through. If an individual incentive group decides to make random moves to explore more of the problem space, this potentially places group members at a disadvantage, because they would be giving up their current set of cards, or their current possible solution that they are trying to achieve. Group incentive groups, however, have more freedom to make random moves due to the lack of consequence of giving up their cards.

It is riskier for individual incentive groups to explore the problem space because this would entail making random card trades. Individual incentive groups may not want to explore the problem space because they might not be able to get their cards back. In addition, they might be less willing to disclose information due to the risky nature of another participant being stuck in the blind alley, leaving the other participants without solutions. Individual incentive groups are trying to achieve the best category, and make the best moves possible to ensure that they reach their desired solution, rather than put them in a position where it might be more difficult to reach a solution. It was therefore hypothesized that individual incentive groups would have less 5a codes compared to group incentive groups, who would be more likely to be willing to explore the problem space. It was also hypothesized that individual incentive groups would have more 5b codes, because of their unwillingness to make random moves and explore more of the problem space.

3.5.2 Results of groups' willingness to explore

The results of the differences in exploration behaviours between group incentive types are shown in **Table 5**. Code 5a, which measured participants willingness to explore the problem space, was significantly different ($p \leq 0.1$) between incentive types. Individual incentive groups had less of the code (M=0.34) than group incentive groups (M=1.92), however only 4 of the 12 individual incentive groups, and 8 of the 12 group incentive groups, had the code overall. When standardized for time, the results still remained significant ($p \leq 0.1$), which indicates that regardless of the amount of time participants took to solve the problem, individual incentive groups always chose to explore less of the problem space. Code 5b, which measured participants unwillingness to explore the problem space, was not significantly different ($p > 0.1$) between group types. Only 2 of the 12 individual incentive groups, and 1 of the 12 group incentive groups had the code overall. Individual incentive groups had the same average number of 5b codes (M=0.34) compared to group incentive groups (M=0.34). When standardized for time, the results remained consistent. ($p > 0.1$)

	Individual	**Group**
Mean frequency of Code 5a SD	0.34 0.49	1.91 1.83
	T-Test	
Degrees of freedom P(T ≤t) two-tail	13 0.013	
Mean frequency of Code 5a/sec	7.29×10^{-4}	3.01×10^{-3}

SD	$1.22x10^{-3}$	$3.19x10^{-3}$
	T-Test	
Degrees of freedom P(T ≤t) two-tail (per sec)	14 0.036	
Mean frequency of Code 5b SD	0.34 0.65	0.34 1.16
	T-Test	
Degrees of freedom P(T ≤t) two-tail	17 1	
Mean frequency of Code 5b/sec SD	$4.5x10^{-4}$ $8.46x10^{-4}$	$4.9x10^{-4}$ $1.708x10^{-3}$
	T-Test	
Degrees of freedom P(T ≤t) two-tail (per sec)	16 0.94	

Table 6. Results of Code 5a, 5b: Exploration.

The results of codes 5a and 5b indicate that individual incentive groups make less verbally explicit exclamations that they are willing to explore the problem space, but both types of incentive groups are equally likely to express that they are unwilling to make exploratory moves. In both incentive conditions, group members may be unlikely to state their unwillingness to explore because of the social pressures acting on them within the group. Groups may feel socially influenced to be cohesive and act the way that the rest of the group is acting. In addition, the lack of significance of code 5b may be due in part that 5b was only used as a response to 5a. For example, when one participant would say “Lets trade and just see what happens”, this would be coded as 5a. If participants said “No, I don’t want to trade” following this, then it would get coded as 5b. There were no explicit stand-alone statements that participants made that indicated that they were unwilling to explore the problem space.

Since not all groups explicitly stated whether or not they were willing to explore the problem space by making random card trades, these thematic codes were not necessarily a complete representation of this concept. Another way to measure this in future experiments may be by asking participants to rate how much they would be willing to explore more of the problem space in a post-experimental questionnaire. This should be adopted in future experiments.

It can also be said that groups' willingness to explore the problem space does not directly relate to a better understanding of the problem structure. In this experiment, individual incentive groups were found to be less willing to explore the entire problem space, but still performed better, and had more frequent problem structure awareness codes (code 2c).

3.6 Uncertainty

Problem solving has been viewed as a process of reducing uncertainty. At the initial state of a problem is the maximum amount of uncertainty. As problem solvers navigate through the problem, they are eliminating uncertainty, and are able to represent barriers and constraints better. It was observed that some groups acted differently when they were stuck in the blind alley and when they completed the experiment. When groups were stuck in the blind alleys, the other two participants who did not possess the appealing blind alley categories either realized that the group needed to detour, or they attempted to create a category out of the cards in front of them. Some of the groups adapted abstract card categories in order to fit the unmatching cards that they had, but felt very uncertain about these categories. They would express their uncertainty by saying phrases such as "I don't think this is going to work". In other instances, some groups found certain correct categories to be more appealing than others. For example, a group was very uncertain that three chairs and a coat hanger would be matched together in a category (i.e. furniture), and ended up playing rock-paper-scissors to fairly determine who would get this category. At the end of the experiment, when they indicated that they were finished, the participant with the furniture category exclaimed “I think I’m done but I’m not sure”. To account for this phenomenon of uncertainty, code 9 was used anytime participants made explicit statements that they were unsure of their category.

Accounting for uncertainty would also help determine if groups were making calculated moves based on their understanding of the problem structure. If groups were adequately thinking through the problem, and determined 4 correct categories, then they would be more certain that their solution is correct, and take a more direct path to the solution.

3.6.1 Hypothesis of group’s uncertainty of the solution

It was hypothesized that individual incentive groups would be more certain about their categories and the moves that they make. This is because individual incentive groups are known to make fewer errors (i.e. get stuck in fewer blind alleys), and therefore they may be taking more of a direct and well-calculated path to the solution. It was therefore predicted that individual incentive groups would have less code 9 compared to group incentive groups.

3.6.2 Results of group’s uncertainty of the solution

The results of the uncertainties of the different group incentive types can be seen in **Table 7.** There was no significant difference ($p>0.1$) found between individual incentive groups ($M=0.25$) compared to group incentive groups ($M=0.59$). The results also remained consistent when the code was standardized for time ($p>0.1$).

	Individual	Group
Mean frequency of code 9	0.25	0.59
SD	0.49	0.82
	T-Test	
Degrees of freedom	17	
P(T ≤t) two-tail	0.22	
Mean frequency of code 9/sec	0.0002	0.0009
SD	0.0015	0.004
	T-Test	
Degrees of freedom	13	
P(T ≤t) two-tail (per sec)	0.15	

Table 7. Results of code 9: Uncertainty.

Although the results did not show any significant differences between groups, it should be noted that only 3 of the 12 individual incentive groups, and 5 of the 12 group incentive groups had this code. Of all the groups combined, the means of these codes for each group incentive type was less than 1 (M=0.25, M=0.59), which does not provide enough data to be able to test for differences. Participants in both sets of groups did not explicitly exclaim how they felt about their categories. In future experiments, a post-experimental questionnaire should ask participants how confident they were in the category solution that they had. However, in order to further test whether there are any differences between groups, an additional test was completed on the time between when groups had the correct solution, and when they told the experimenter that they were done. These results can be seen in **Chapter 4**.

3.7 Solution Paths

The paths to the solution that each group took, termed here as "solution paths, were analyzed through the thematic coding. When watching the first four experimental videos, it was clear that most groups tended to solve the problem in three different stages: predicting the solution, moving towards the solution, and stating that they had the solution. This was shown by codes 6, 7 and 8. Code 6 was used anytime a participant made an inference about what they thought a solution category could be. This included phrases such as “If we use the bridges and the pyramid, then maybe we can say it’s structures”. Code 7 was used anytime a participant made an explicit exclamation about wanting to make a move towards the solution (i.e. trade a card). This included phrases such as “Give me your chair and I’ll give you my sweater”. Lastly, code 8 was used anytime participants indicated that they had collected a solution. This included phrases such as “I have four costumes”. To visually represent the entirety of the solution path, and to identify which groups had more direct solution paths, codes 6, 7 and 8 were graphed together.

3.7.1 Hypothesis of Solution Path

Similar to previous hypotheses, due to the risky nature of being in an individual incentive group, it was predicted that this type of group would have a more direct solution path. Individual incentive groups would be less likely to explore the problem space, and therefore have less solution predicting codes, code 6, compared to group incentive groups. Individual incentive groups will be more likely to have an organized pattern, where they would first predict the four solution categories, then begin trading. This would ultimately help them avoid getting stuck in blind alleys, or have other participants be unwilling to trade once they have their own solution. It was therefore predicted that solution prediction codes, code 6, would primarily be at the beginning of the timeline of individual incentive group’s solution paths. On the other hand, group incentive groups would be more willing to explore the problem space, and make therefore make new predictions of the solution as they gained more information. If group incentive groups were more frequently stuck in blind alleys, this would also mean that they would have to make more solution predictions compared to individual incentive groups. It was therefore hypothesized that group incentive groups would have more code 6, and it would appear throughout a majority of those groups' solution timelines.

Individual incentive groups also made fewer exchanges compared to group incentive groups. It was therefore hypothesized that individual incentive groups would have fewer negotiations and comments of solution moves, code 7, compared to group incentive groups. It was also hypothesized that group incentive groups would have more code 7 throughout the majority of their solution timeline, while individual incentive groups would have code 7 more in the middle of their solution timeline, after code 6 appeared.

Lastly, group incentive groups were stuck in blind alleys more often than individual incentive groups, which would indicate that group incentive groups falsely believed that they had the correct solution more times than individual incentive groups. It was therefore hypothesized that group incentive groups would have more statements that they had the solution, code 8, compared to individual incentive groups. It was also hypothesized that code 8 would appear in a larger time range in group incentive groups; solution timelines compared to individual incentive groups.

3.7.2 Results of Solution Path

The results of the comparisons of code frequencies for codes 6, 7 and 8 are shown in **Table 8.** Code 6, which was used whenever participants made inferences on what a possible category could be, was not significantly different ($p>0.1$) between individual incentive groups ($M=25.59$) and group incentive groups ($M=24.17$). When standardized for time, the results remained consistent ($p>0.1$). For code 7, which was used whenever participants made exclamations about wanting to make moves towards the solution (i.e. exchange cards), was also not significantly different ($p>0.1$) between group types. When standardized for time, results remained consistent ($p>0.1$). For code 8, which was used anytime a participant exclaimed that they had a complete solution category, there was a significant difference ($p\leq 0.05$) between individual incentive groups, who had a lower amount of the code (M=6.08) compared to group incentive groups (M=11.59). When standardized for time, the results remained consistent ($p\leq 0.1$).

	Individual	**Group**
Mean frequency of Code 6	25.59	24.17
SD	13.78	14.15
	T-Test	
Degrees of freedom	22	
P(T ≤t) two-tail	0.81	
Mean frequency of Code 6/sec	0.043	0.034
SD	0.016	0013
	T-Test	
Degrees of freedom	21	
P(T ≤t) two-tail (per sec)	0.13	
Mean frequency of Code 7	21.25	28.08
SD	8.66	21.42
	T-Test	
Degrees of freedom	14	
P(T ≤t) two-tail	0.32	
Mean frequency of Code 7/sec	0.038	0.038
SD	0.016	0.015
	T-Test	
Degrees of freedom	22	
P(T ≤t) two-tail (per sec)	0.98	

Mean frequency of Code 8 SD	6.08 4.46	11.59 5.99
	T-Test	
Degrees of freedom P(T ≤t) two-tail	20 0.019	
Mean frequency of Code 8/sec SD	0.012 $9.41x10^{-3}$	0.017 $7.47x10^{-3}$
	T-Test	
Degrees of freedom P(T ≤t) two-tail (per sec)	21 0.1	

Table 8. Results of Code 6, 7 and 8 frequencies: Solution Path.

The lack of significant difference for both codes 6 and 7 between group incentive types, indicates that groups did not display different solution prediction and solution move behaviours even when other factors such as awareness and understanding of the problem structure, information sharing, and willingness to explore were present. However, because there is a minimum amount of category prediction and solution moves that needs to occur in order to solve the problem, it is understandable that both group types have similar quantities of codes 6 and 7. In order to solve the problem, groups must work collectively and make trades. Since both incentive group types solved the problem, this would indicate that they both would have to engage in the same type of quantitative behaviour. If group incentive group types made more card trades, but still had a similar amount of code 7, this would indicate that they were trading without thinking out the exchanges beforehand. The same might be true for code 6. If group incentive groups were engaging in more random, and less direct behaviour, then they would be making fewer solution predictions (code 6), and instead be trading randomly as a means of information exchange.

To gain a better understanding of the types of solution paths that groups took, and if individual incentive groups took a more direct path to the solution, I graphed the cumulative frequency distribution of codes 6,7, and 8, alongside the card exchanges that each group made, over each groups' timeline. These codes were graphed in terms of when they appeared throughout the experimental transcript for each group. The x axis represents the timeline of the experiment on a scale of 0-1. This was done in order to standardize the timeline of each of the groups. The y axis represents the cumulative frequencies of each code. This was done to account for the differences in quantities of the code, and standardize them across a scale of 0-1. **Figure 8** shows a graph from an individual incentive group that performed the best of all the experimental groups. This group did not enter any blind alleys, made 12 card exchanges (the minimum number of card exchanges needed to solve the problem), and completed the problem in the shortest amount of time, 316 seconds. **Figure 9** shows a graph from approximately the middle range of performance. This graph is from a group incentive group which got stuck in a blind alley 2 times, exchanged cards 20 times, and took 531 seconds to solve the problem. **Figure 10** shows a graph from a group incentive group that performed the worst. This group was stuck in a blind alley 8 times, exchanged cards 60 times, and took 1523 seconds to complete the experiment. This group also failed to correctly label the solution categories.

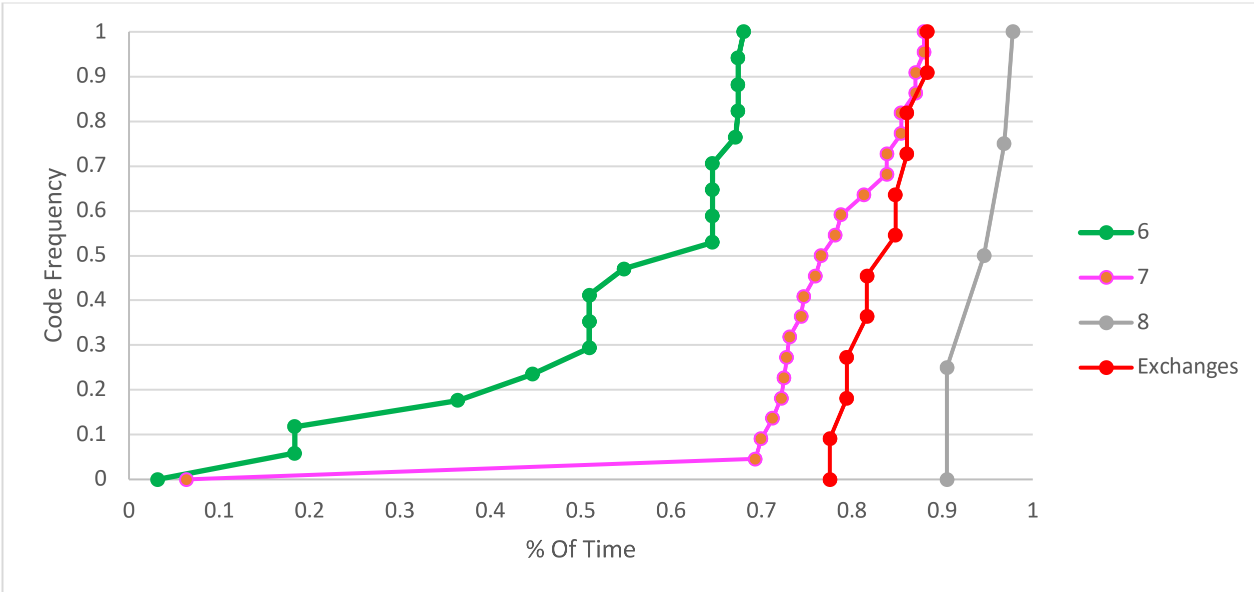

Figure 8. Graph of solution path (codes 6, 7 and 8) for the best performing group.

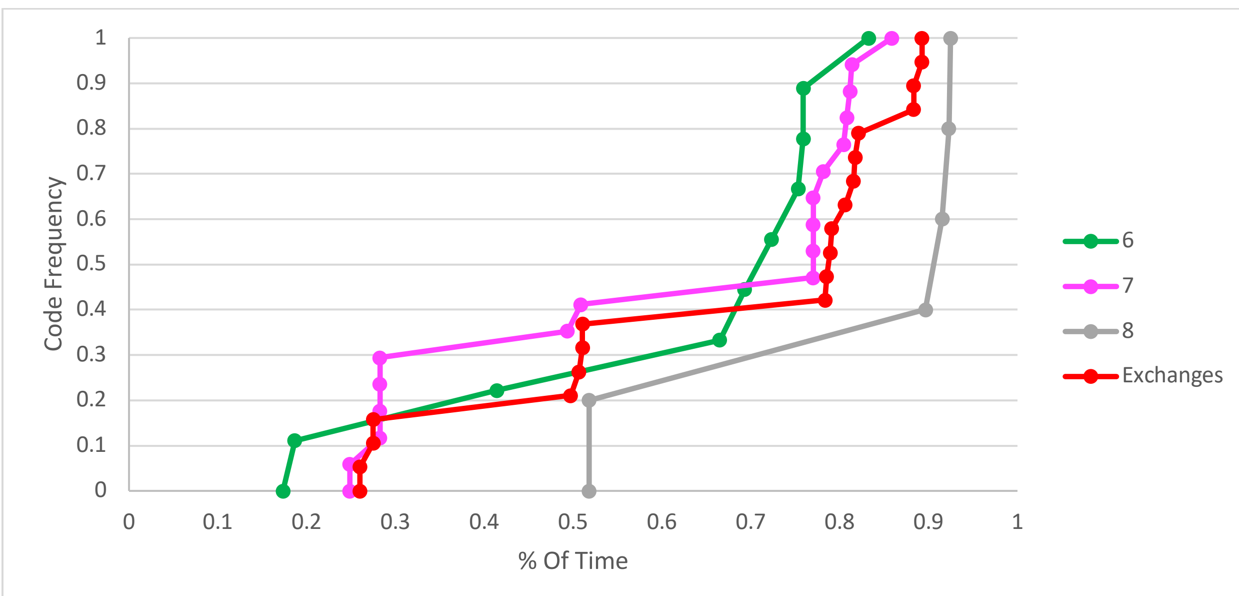

Figure 9. Graph of solution path (codes 6, 7 and 8) for a middle/average performing group.

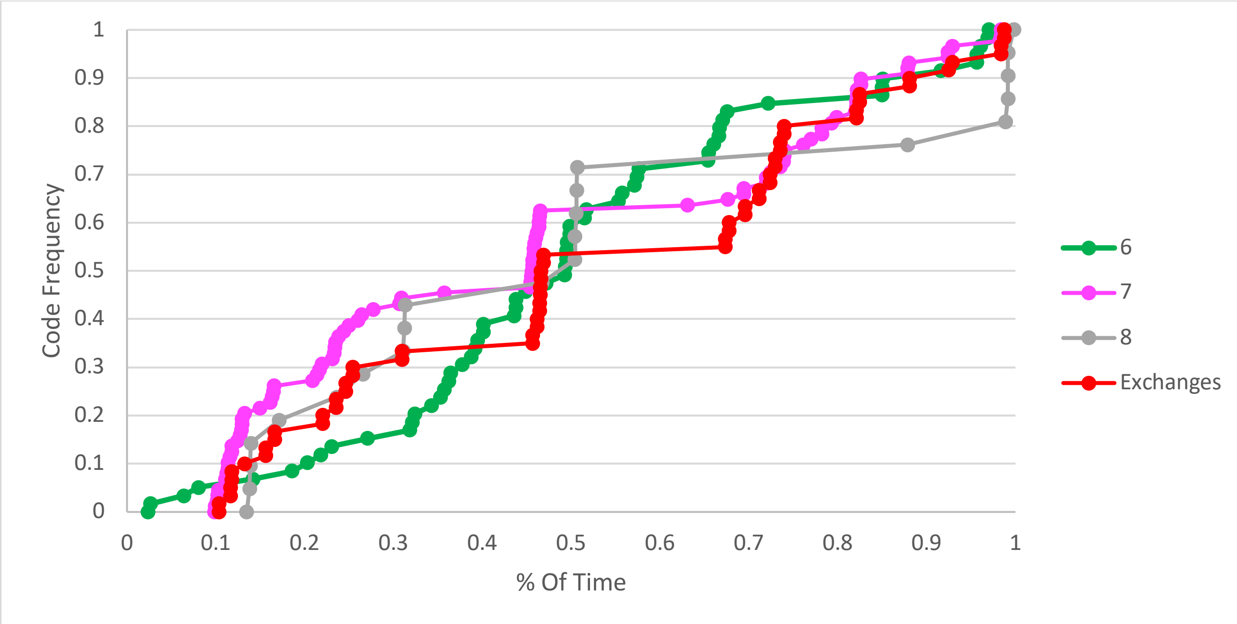

Figure 10. Graph of solution path (codes 6, 7 and 8) for the worst performing group.

When looking at the graphs, the differences in the sequence in which the codes appear becomes obvious. In the best performing group, an individual incentive group, there is a clear separation between codes 6, 7 and 8. First code 6 appears, then code 7, then card exchanges, followed by code 8. It appears as though groups are making predictions of what they think the correct 4 categories are, negotiating and deciding who will collect each category, making the exchanges for that category, and then finally stating that they each possess the solution.

In the average performing group, a group incentive group, the lines that represent each of the codes begin to become less distinct. Although code 6 appears first, it continues throughout most of the graph. This means that groups are making predictions for solution categories throughout the experiment, and therefore might not be certain of the solution itself. Code 7, indicating negotiations and card move decisions, also appears throughout most of the graph. This indicates that groups are negotiating about trading for cards, and may therefore be making random moves. In a more rational approach, one would expect to see code 6 before code 7, since participants should be identifying categories first, then trading. If participants are trading blindly, then this would leave them with no other option than creating categories from the new set of cards that they have in front of them. Lastly, code 8 appears in the middle of the graph, and continues throughout. This indicates that some of the participants thought that they were done collecting a solution, but were not (i.e. they were either incorrect, or uncertain of their solution).

In the worst performing group, a group incentive group, the lines that represent each of the codes are completely overlapping one another. All codes appear throughout the entirety of the experiment. This group was stuck in the blind alley for a total of 8 times, and made 60 card exchanges, which indicates their struggle to find the solution. Viewing the disorderly conduct of their solution path, it is also evident that this group was not taking a direct path, and might have been randomly trading cards, and making incorrect inferences on the solution categories.

To further compare the differences in solution paths between group incentive types, analyses were done to identify the duration of the codes in each of the problem solving timelines. The codes were standardized for time, and the first code (calculated by the percentage of time of the specific group's timeline where it first appeared) was subtracted from the last code appearance to create a range. Time ranges were then compared between group incentive types. The average of each of the means of each code was also calculated to compare where in the experimental timeline the code appears most. The results of these comparisons are shown in **Table 8**.

	Individual	Group
Mean frequency of the time range of code 6	0.65	0.79
SD	0.21	0.11
Mean time of code 6	0.47	0.51
	T-Test	
Degrees of freedom	17	
P(T ≤t) two-tail	0.05	
Mean frequency of the time range of code 7	0.48	0.64
SD	0.27	0.16
Mean time of code 7	0.53	0.56
	T-Test	
Degrees of freedom	18	
P(T ≤t) two-tail	0.1	
Mean frequency of the time range of code 8	0.18	0.61
SD	0.24	0.21
Mean time of code 8	0.75	0.75
	T-Test	
Degrees of freedom	22	
P(T ≤t) two-tail	0.0001	

Table 8. Results of the time range and mean time of codes 6, 7 and 8 in the solution path timeline.

For code 6, which was used anytime a group made a prediction of what a possible solution category could be, the results show that there was a significant difference (p≤0.1) for the time range in which the code appears between individual incentive groups (M=0.65) and group incentive groups (M=0.79). The range for individual incentive groups is much shorter, which indicates that these groups spent less of the entire time predicting solutions. The average of code 6 for individual incentive groups (M=0.47) shows that it appears earlier in the timeline compared to group incentive groups (M=0.51). This indicates that individual incentive groups are spending more of the beginning of the experiment making predictions.

For code 7, which was used anytime a group was making a decision on which participant would collect a category or card, there was a significant difference ($p \leq 0.1$) for the time range in which the code appears between individual incentive groups (M=0.48) and group incentive groups (M=0.64). Individual incentive groups had a smaller range, indicating that they were making decisions to trade cards more concisely. Since individual incentive groups performed better, this indicates that they might have correctly identified the solution categories, and agrees on card trades more efficiently after their predictions. This shows a more direct solution path.

Lastly, for code 8, which was used anytime participants had indicated that they had finished collecting a solution category, the results showed that there was a significant difference ($p \leq 0.1$) between individual incentive groups (M=0.18) and group incentive groups (M=0.61). The time range for individual incentive groups was much smaller than group incentive groups. This might have been because individual incentive groups made less errors compared to group incentive groups, and when they subjectively thought they had correctly identified the solution, they were correct. On the other hand, because group incentive groups fell into blind alleys more frequently, when they had identified their solution categories, they realized they were incorrect, and had to start the process over again. This would mean that they would have to make solution category predictions again (code 6), then negotiate trading again (code 7), and finally, re-state their collected categories (code 8). This may explain why these three codes appear throughout the entire experimental timeline, where as compared to individual incentive groups, the three codes appear in progressing order.

An additional test measuring whether these codes truly indicate how direct or indirectly groups reached a solution was developed to go alongside this coding. The additional analysis identifies the category labels that participants used throughout the experiment, and assigns numbers based on if the labels are correct or incorrect, and then plots this over the time of the experiment. The results of this analysis is reported in **Chapter 4**.

3.8 Results Overview

In this chapter, I discussed the results of the thematic codes, and used t-tests to analyze whether there were differences between the two incentive type groups. Information processing was demonstrated through memory and information sharing. Code 1, which was used when participants made explicit exclamations that they were struggling with memory, was not significantly ($p>0.1$) different between group types. The results remained consistent when standardized for time. In **Chapter 4**, this concept will be explored further with other quantitative measures.

Problem structure, was measured by codes 2a, which was used when groups were aware of the blind alleys, 2b, which was used when groups were aware of restructuring (i.e. the solution categories were made up of 3 similar items and 1 dissimilar item), and 2c, which was used in other general awareness of the problem structure. Code 2a, which only appeared in 4 of the 24 group transcripts, showed no significant difference ($p>0.1$) between group incentive types, and the results remained consistent when standardized for time. Code 2b, which only appeared in 16 of the 24 group transcripts, showed no significant difference ($p>0.1$) between group incentive types, and the results remained consistent when standardized for time. Code 2c, which appeared in all transcripts, showed no significant difference ($p>0.1$) between group incentive types, but was significantly different ($p \leq 0.1$) when standardized for time. Individual incentive groups had more of this code compared to group incentive groups. The combined code of 2a, 2b and 2c were significantly different ($p \leq 0.1$), indicating that individual incentive groups understand more of the problem structure compared to group incentive groups.

Information sharing was demonstrated by codes 3a, which was used when participants asked for information, and 3b, which was used when participants gave information. For code 3a, there was no significant difference ($p > 0.1$) between group incentive types, and remained consistent when standardized for time. However for code 3b, there was a significant difference ($p \leq 0.1$) between incentive type groups, as individual incentive groups had less of this code, and the results remained consistent when standardized for time.

Communication was attempted to be captured by codes 4a, which was going to be used when groups used a more cohesive “we” language, and 4b, which was going to be used when groups used a more individualistic language. However, these codes were ultimately not tested because coding them was too subjective. Code 4c, which was used anytime group participants spoke over one another and words were unable to be transcribed in the videos, was significantly different ($p \leq 0.1$) between incentive type groups, as group incentive groups had more of this code.

Exploration was demonstrated by codes 5a, which was used when participants were willing to make random trades and explore the problem space, and 5b, which was used when participants were unwilling to explore. Code 5a was significantly different ($p \leq 0.1$) between group types, as group incentive groups had more of the code, and the results remained consistent when standardized for time. Code 5b was however, not significantly different ($p > 0.1$) between group types, and these results remained consistent when standardized for time.

Uncertainty, which was shown with code 9, was used when participants made explicit statements that they were unsure of the solution category that they had. When tested, there was no significant difference ($p>0.1$) between group incentive type, and these results remained consistent when standardized for time. In **Chapter 4**, this concept will be explored further with other quantitative measures.

Lastly, the solution paths that the groups took was captured by codes 6, 7 and 8. Code 6 was used when participants made predictions of solution categories, code 7 was used when participants would decide who would collect specific cards, and code 8 was used when participants would exclaim that they acquired a solution category. Differences of solution paths were tested in two ways: through comparing the frequencies of these codes between group types, and comparing the time ranges of these codes between group types. For frequencies, codes 6 and 7 were not significantly different ($p>0.1$) between group incentive types. But, code 8 was found to be significantly different ($p\leq0.1$) between incentive types, as individual incentive groups had a lower amount of this code. For time ranges, each of codes 6, 7 and 8 were significantly different ($p\leq0.1$) between group incentive types. Individual incentive groups had a smaller time range for each of these codes, and also had a smaller mean for these codes. These results also indicate that individual incentive groups had a more organized strategy, and didn't go back and forth between predicting solutions, moving towards a solution, and stating that they have a solution. The concept of solution paths will be continued to be explored in **Chapter 4**.

Chapter 4: Additional Thematic Topic Analyses, Solution Path Analysis, and Ranked Performance Results

In the previous chapter, the hypotheses and results of the thematic codes that were developed were discussed. Although some of the thematic codes yielded significant results, it was still difficult to demonstrate and test the ideas and concepts surrounding how groups solve problems when given different incentives. To move the research field forward, the aim of this study was to gain a deeper understanding of the processes and pathways that groups take to solve problems. This includes investigating the underlying cognitive and social mechanisms that groups use while processing problems. This chapter is divided into three different sections. In the first section, the additional quantitative tests that were done on a few of the themes developed from the thematic codes will be reported. In the second section, the additional test done on the group's different solution paths will be reported. In the last section, groups are ranked based on performance, and the differences between each factor are analysed.

4.1 Part One: Results of Experimental Analyses and Thematic Topic Analyses

The results reported in this section pertain to both the themes from the thematic coding scheme, and additional tests done on the overall experiment. In the first section, additional results on the experiment are shown. This includes a comparison of problem solving time, card exchanges, and standard deviations of the timing of card exchanges. In the second section, all additional results done on the thematic code themes are shown.

4.1.1 Experimental Analyses

Although Chen (2010) reports the differences in problem solving time and card exchanges, this data was reanalyzed in the current experiment. Explanations and details as to why this was done, and the outcome of the results, are reported in this section.

4.1.1.1 Problem Solving Time Results

The time that participants took to solve the problem was also re-analyzed from Chen's (2010) experiment. This was due to the differences in time in the transcribed videos. Chen (2010) began her time when the experimenter indicated the time on the clock during the experiment, whereas the transcripts began with the first words that the participants said. The beginning time of the experiment was therefore changed to match with the transcripts, which was when the first participant spoke. The time of the experiment was re-calculated to ensure that Chen's (2010) conclusions would be valid, even though they are measured in a different way. Although time is a seemingly objective measure, it can still be interpreted in different ways (i.e. the different way in which time was calculated for this experiment). The results of the comparison in the time it took the different group types are shown in **Table 9**.

	Individual	**Group**
Mean time that groups took to complete the experiment (in seconds)	665.42	723.5
SD	369.28	325.94
	T-Test	
Degrees of freedom	22	
P(T ≤t) two-tail	0.68	

Table 9. Results of the re-analysis of the experimental times.

Consistent with Chen's (2010) results, there was no significant difference ($p>0.1$) between individual incentive groups ($M=665.42$) and group incentive groups ($M=723.5$).

4.1.1.2. Card Exchanges

In Chen's (2010) experiment, card exchanges were counted only when one participant would hand over a card, and another participant would take this card. At the beginning of the experiment, the participants were instructed that they could only physically give one another cards, and they were not allowed to show each other their cards without giving it away. However, while transcribing the experimental videos, it became apparent that there were many instances where group members would show one another their cards without physically giving them to the other group member. Such card showing behavior was not counted by Chen (2010) as card exchanges. In order to maintain objectivity of card exchanges, and stay true to the experimental design, any time a card was placed beyond the T-barrier, it would be counted as a card exchange. This guaranteed that when group participants wanted to show each other their cards, this would be given an equal weight as giving away information through a physical card exchange. A true card exchange involves giving a card and receiving either a different card, or the same card back, and would be therefore counted as 2 exchanges. However, showing another participant a card without giving it away (i.e. placing a card beyond the T-barrier) was only counted as 1 exchange. This was done to ensure that showing cards would not be equal to the stronger commitment of giving a card away, and receiving another (or the same) in return. The results of the comparison of card exchanges between group types can be seen in **Table 10**.

	Individual	Group
Mean card exchanges	18.75	33.58
SD	8.43	16.07
	T-Test	
Degrees of freedom	17	
P(T ≤t) two-tail	0.01	

Table 10. Results of the re-analysis of card exchanges.

Consistent with Chen's (2010) results, there was a significant difference (p≤0.1) between individual incentive groups (M=18.75) and group incentive groups (M=33.58), as group incentive groups made more card exchanges.

4.1.1.3. Standard Deviation of the Timing of Card Exchanges

To understand the differences between group problem solving behaviours, the solution path was investigated in the thematic coding scheme, as detailed in **Chapter 3**. This was divided into codes 6, 7, and 8, which was used to map when groups made solution predictions, solution moves, and solution statements. These codes were plotted onto graphs in order to gain a better understanding of how groups are behaving while solving problems. There were significant differences found between group incentive types and the time range in which they spent in each of these problem solving stages. Group incentive groups tended to solve problems by making predictions, solution moves, and solution statements throughout most of the problem solving process. This might either be the cause of, or consequence of, the larger amount of errors that group incentive groups are prone to make. Factors such as a weaker understanding of the problem structure, more instances where participants speak over one another, and a greater willingness to make random moves to explore more of the problem space, may contribute to why group incentive groups make more mistakes.

To confirm that group incentive groups solve problems in a less direct manner, and behave differently compared to individual incentive groups, the standard deviations of the timing of card exchanges were calculated. This was done by taking the standardized time on a scale of 0-1 of each card exchange, calculating the SD of these data points for each group, and then averaging across the different incentive types. Measuring the distribution of times when card exchanges occurred over a timeline will give an indication of how groups are trading cards. A lower SD shows that groups were not trading randomly throughout the experiment, but were instead being more direct with their solution moves. This is because a lower SD indicates that the card exchanges are occurring closer to the mean point, and therefore in a more narrow time range. Individual incentive groups were hypothesized to have a lower SD because their card exchanges were predicted to be taking place mostly in the middle of the problem solving process. Individual incentive groups are spending more time thinking about their predictions for a solution and working out the problem structure. They would be more likely to exchange cards only when they are certain there is no risk, or in other words, once they believe they know the correct solution. This would therefore show a more narrow cluster of card exchanges. Group incentive groups were hypothesized to a have higher SD because their card exchanges would be taking place throughout the entire problem solving process, more randomly. First, groups should identify the categories that they would like to use as a solution, then they should be making trades. Group incentive groups would be more likely to make card exchanges throughout the entirety of the experiment because of their willingness to explore the problem space, and reduce their memory and information processing load. The results of the standard deviations of the timing of card exchanges are reported in **Table 11**.

	Individual	**Group**
Mean SDs of the timing of card exchanges	0.13	0.23
SD	0.10	0.04
	T-Test	
Degrees of freedom	15	
P(T ≤t) two-tail	0.006	

Table 11. Results of the standard deviations of the timing of card exchanges.

As previously predicted, there was a significant difference ($p \leq 0.1$) between individual incentive groups (M=0.13) and group incentive groups (M=0.23), who had a higher standard deviation of the timing of card exchanges. Since this standard deviation is higher, this means that group incentive groups were trading cards over a wider range of time. This might indicate that groups are making more random trades, and are not carefully thinking out which cards they must be trading in order to get to the solution. One possible reasoning for this may be that group incentive groups have less consequential risk when trading cards. They are open to giving cards to one another, which also reduces their cognitive load. Group incentive groups may be incentivized to trade cards as this is another way of information processing. Rather than discussing which items they have on their cards, it may be easier for them to simply just trade. Group incentive groups are also more willing to trade their cards before they have predicted a solution, while individual incentive groups might avoid trading until they are sure that they will achieve a solution. This measure ultimately confirms the difference in behaviour in how different incentive types affect groups.

4.1.2 Additional Thematic Topic Analyses

Supplementary tests were created in order to investigate some of the themes that the thematic codes were unable to capture (**see Chapter 3**). We were unable to develop supplementary tests for all themes, due to the nature of the experiment and methodology. The additional quantitative tests that were used are reported in this section.

4.1.2.1 Memory: Category Label Repetitions

To investigate whether incentives had an effect on the memory load of participants, code 1 (**Chapter 3.1**) was used to anytime a participant exclaimed that they were having troubles remembering an item, category, or keeping other information in their memories. In the experiment, participants could process information in one of two ways: they could either exchange cards, or verbally dictate which items they had. Individual incentive groups were found to trade cards less frequently, and were therefore hypothesized to have to dictate their cards items more, and therefore keep more items in their memories. Unfortunately, participants did not frequently exclaim that they were struggling with their memories, and therefore the code was unable to generate enough data to test the hypothesis. In addition to the memory code, the amount of times participants repeated words used for items and category labels were averaged for each group to test how frequently groups repeated these words. If groups had to repeat more words, this would indicate that they were struggling to remember the items and categories that were being discussed. It was hypothesized that individual incentive groups would have more word repetitions, due to the lack of cards that were exchanged, and the increased struggle on their memories to process the information that they were discussing. The results of the repeated words are reported in **Table 12.**

	Individual	**Group**
Mean of average word (item/category label) repetitions	5.41	6.72
SD	1.76	1.87
	T-Test	
Degrees of freedom	22	
P(T ≤t) two-tail	0.08	

Table 12. Results of word repetitions of groups.

Contrary to the hypothesis, there was a significant difference ($p \leq 0.1$) between individual incentive groups (M=5.41) and group incentive groups (M=6.72) word repetitions. Group incentive groups had larger average word repetitions, which may indicate that they had a more difficult time remembering these words. Although, it should be noted that in the present experiment, due to the collaborative nature, there is a minimum amount of words that participants have to discuss in order to share information. This minimum number could also change, depending on the amount of cards that participants exchange. For example, if participants exchange less cards, then perhaps they would have to discuss more words in order to relay the same amount of information as groups that are exchanging more cards. Due to the minimum number of words required to solve the problem, this measure was not standardized for time. It is difficult to test whether this type of test truly indicates a memory struggle. A more effective way to test this might be to ask groups to recall the items that they remember in a post-experimental questionnaire, or to ask group members to rate their feelings of memory struggle in a post-experimental questionnaire.

In this test, individual incentive groups might have a lower number of average repeated words because they are less inclined to share information. Individual incentive groups may be sharing a lower amount of information, perhaps closer to the minimum amount to reach the solution, because of the risky nature of disclosing items. If individual incentive group participants disclose more information to each other, then they might risk another participant asking for their card item.

4.1.2.2 Uncertainty

Uncertainty was tested in the thematic coding scheme by a code that was used anytime participants explicitly stated that they were uncertain about a solution category (**Chapter 3.6)**. Unfortunately, participants did not frequently make these types of exclamations, and the code did not generate enough data to test if there was a difference between groups. As an additional measure, the time between when groups reached the correct final solution, and the time that participants indicated to the experimenter that they were finished, was calculated. This time bracket indicates how long groups spent discussing the confirmation of their categories, and therefore if the time was longer, then this would indicate that they were less confident of their solution. It was previously hypothesized that individual incentive groups would be more certain of their categories, due to the more direct path and calculated moves that they made to reach the solution. Therefore, individual incentive groups should have a shorter time between when they had the final solution, and when they stated that they were finished. The results of this test are shown in **Table 13.**

	Individual	**Group**
Mean of the time between when groups had the final solution and when they stated they were done (in seconds)	174.67	205.67
SD	172.82	735.35
	T-Test	
Degrees of freedom	20	
P(T ≤t) two-tail	0.71	

Table 13. Results of uncertainty times.

The results indicate that there was no significant difference (p>0.1) between individual incentive groups (M=174.67) and group incentive groups (M=205.67). Although this test was put in place to try and gain insight into whether or not there is a difference in feelings of uncertainty between the different group types, there was an experimenter bias present. Groups were originally told that they only had 15 minutes to solve the problem. This was put into place in order to increase the effectiveness of the incentive (Chen, 2010). However, if groups did not solve the problem in this time frame, they were given extra time. Each group was given a different amount of extra time, but this extra time limit was also not kept strict. When groups reached the solution, the experimenter called the time on the experiment. This decreased the amount of time between when groups finally reached a solution, and when they finished the experiment. Ultimately, this test was not able to capture the uncertainty of solution categories by the different groups. In future experiments, the time limit should be kept strict, and feelings of uncertainty should be asked in a post-experimental questionnaire.

4.2 Part Two: Solution Path Analysis

The aim of this study is to identify behavioural differences between how groups process a problem, or in other words, how groups move from the initial problem state to the goal state. To identify behavioural differences in the solution path, both a solution path thematic code and an alternative measure were used. In this section, the alternative measure that was created, a supplementary test measuring how directly or indirectly groups reached their solutions, is shown. In the first section, the results of the solution path analysis are reported. In the second section, Pearson correlations that were calculated between the solution path and factors such as the number of words a group used, the number of card exchanges and the amount of time it took groups to complete the experiment are reported.

4.2.1 Solution Path Analysis

To analyze the difference in behaviour between the group incentive types, an alternative measure was created. First, card items and category labels from each group's transcripts were compiled in the sequence in which they appeared. Then, the words were assigned either a 0, for when they referred to an incorrect solution category or item, or a 1, if they referred to a correct solution category or item. Then, scores were averaged in sequential groups of 10. For example, words 1-10 would the first group, words 2-11 would be the second group, words 3-12 would be the third, etc. This allowed for a moving average across the experimental timeline. Moving averages were then graphed along with when participants made card exchanges. Each time the graph changed direction, either from up to down or down to up, this was counted. The frequency of directional changes was then compared between individual incentive groups and group incentive groups. Graphs for the best performing group, an average performing group, and the worst performing group can be seen in **Figures 11, 12 and 13**.

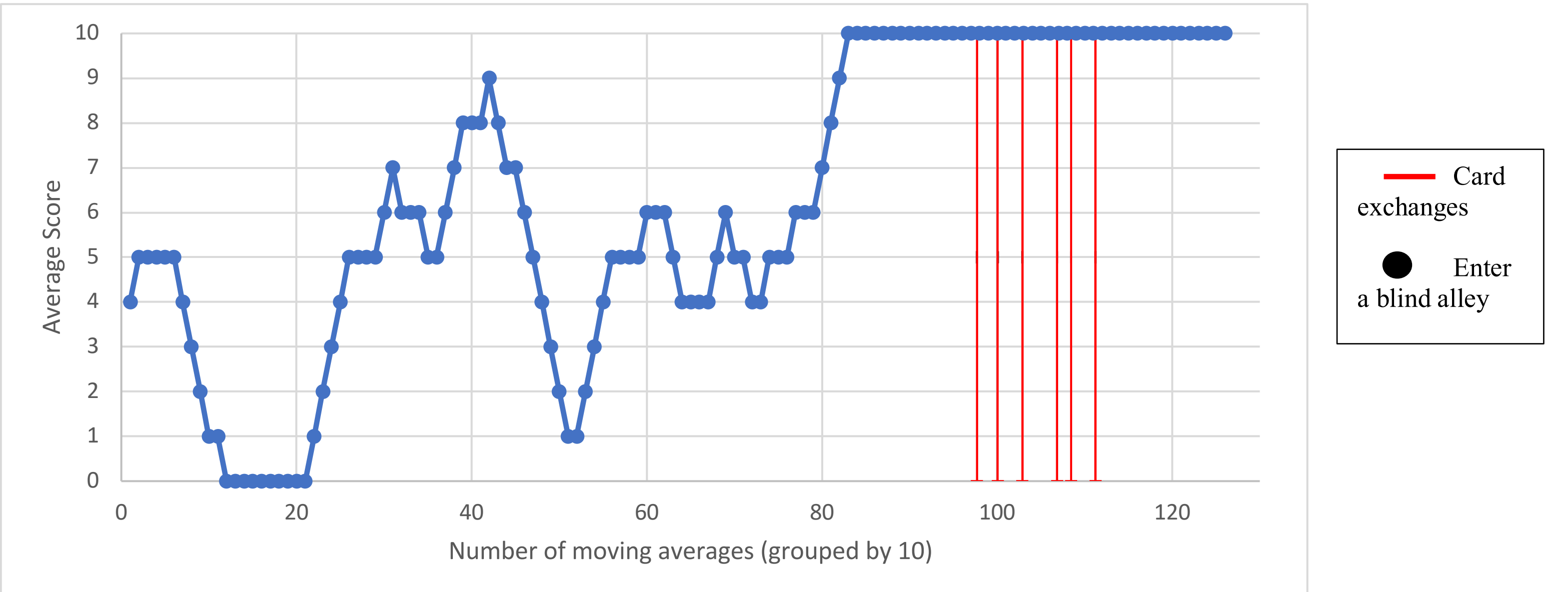

Figure 11. Graph of the best performing group's solution path analysis.

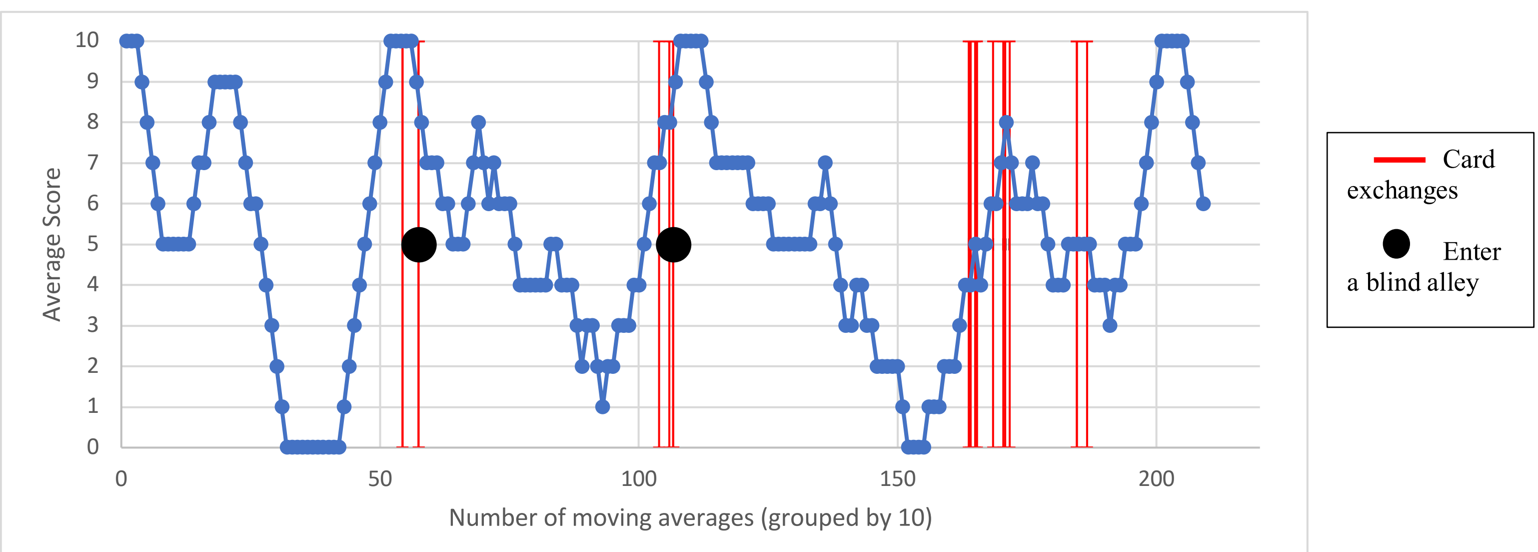

Figure 12. Graph of an average performing group's solution path analysis.

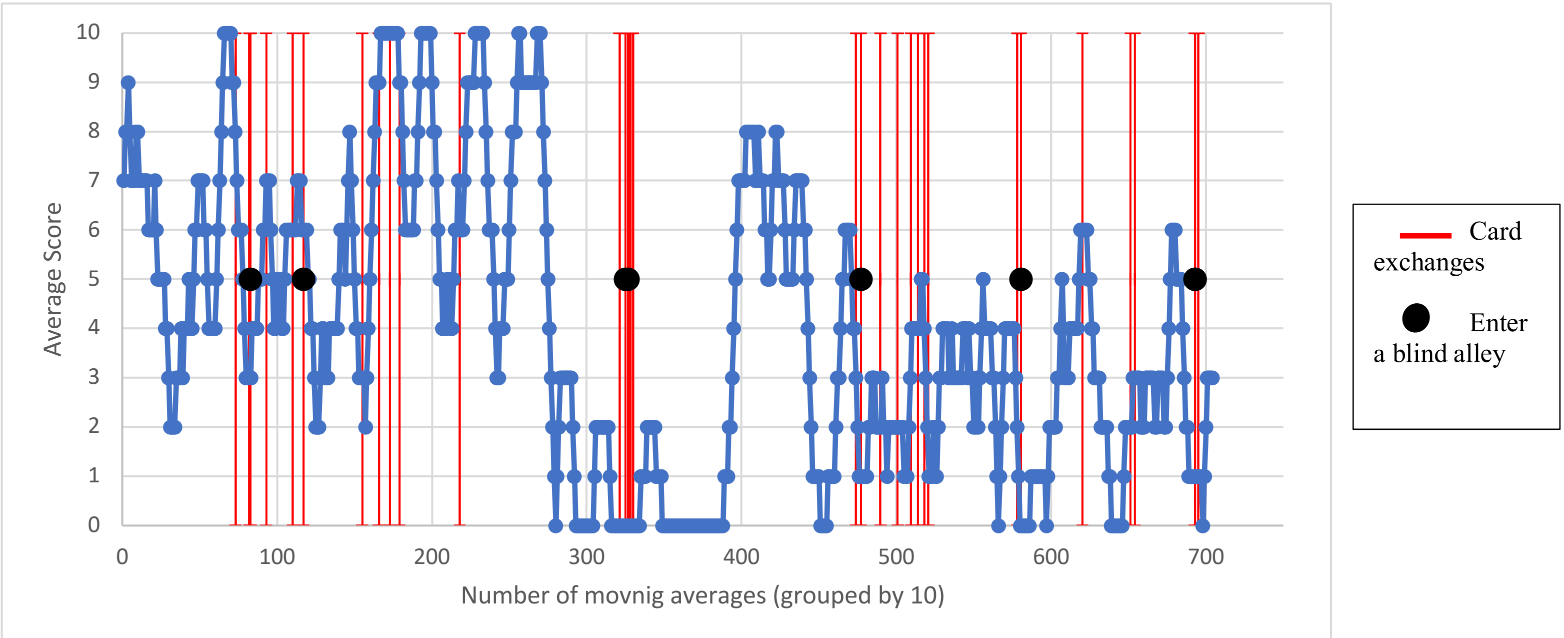

Figure 13. Graph of the worst performing group's solution path (scored).

The number of times the moving average changed in direction was counted for each group. A larger frequency of directional changes indicates that a group is taking a less direct path towards the solution. This might be due to an increased number of card exchanges, more random moves, and an overall less organized pattern of solution prediction, solution moves, and solution statements. Although all groups, except for one, solved the problem, the way in which they solved the problem was different. If the difference in group incentive types can be seen in the solution paths that groups used, then this indicates that incentives have an effect on the cognitive and social mechanisms that underly the process that groups use to solve complex problems. It was hypothesized that individual incentive groups would have a more direct path (less directional changes) compared to group incentive groups. This hypothesis can also be seen in **Chapter 3.7.1.**, where it was hypothesized that individual incentive groups would have a more organized pattern of behaviour when predicting the solution, moving towards the solution, and stating that they have reached a solution. This is due to the risky nature of trading cards in the individual incentive condition, which would therefore force this type of group to make more calculated and thought-out moves.

The results for the comparison of directional changes between individual incentive groups and group incentive groups are reported in **Table 14**.

	Individual	**Group**
Mean directional changes	21.42	35.5
SD	7.5	22.27
	T-Test	
Degrees of freedom	13	
P(T ≤t) two-tail	0.05	

Table 14. Results of the comparison of directional changes in the solution path.

The results show that there was a significant difference ($p \leq 0.1$) between individual incentive groups ($M=21.42$) and group incentive groups ($M=35.5$), who had more directional changes. Confirming the hypothesis, group incentive groups had a less organized behaviour pattern, made more random moves, and reached the solution in an indirect manner.

4.2.2 Solution Path Correlations

Pearson correlations were calculated to identify correlational relationships between the number of directional changes in the solution path and other performance factors. In the first correlation, the differences between the number of different category item words and labels that the groups used were calculated. Group incentive groups seemed to use many more words, not only repeating them, but stating each item and using many category item labels. This aligns with the concept that group incentive groups explore more of the problem space, make more random moves, and are more likely to share information, therefore leading them to a disorganized solution processing behaviour. The results of the Pearson correlation between the number of different category word labels that a group used and the number of directional changes (r=0.91) indicated that there was a significant positive association. This shows that the more words for items and category labels that groups were using, the less directional and organized their pattern of problem solving behaviour. If groups are using more item and category label words, this suggests that groups are exploring more of the problem space, sharing more information, or getting stuck, or in other words not performing as well. Group incentive groups have a more challenging experience achieving a solution. They might be confused or lost on how to reach a solution, and may therefore be saying more category item words and labels. As they search more of the problem space and make random trades and moves in an attempt to discover the correct solution.

Pearson correlations were also calculated between the number of changes in direction during the solution path and card exchanges, (r=0.77), and the number of changing directions in the solution path and the time it took to complete the experiment (r=0.71). Since two aspects are related, then this would imply that exchanging cards more, and taking longer to complete the experiment, can affect the group behaviours and processes used while problem solving. This is another indicator of the behaviour of the different group types. The more directional changes seen in the solution path, the more card exchanges and time it took for groups to solve the problem. Group incentive groups have a higher number of changes in direction in their solution paths, and also have a higher number of card exchanges. This shows that group incentive groups are having more difficulty in finding the correct solution, and have a varied type of behaviour and approach that they take in finding the solution (i.e. they make more card exchanges, and are more willing to make random searches in the problem space).

4.3 Part Three: Overall Ranked Performance

The primary aim of this study was to investigate how incentive affects group problem solving behaviour. Some of the results from the testing done were clear, however others were ambiguous due to the measurement difficulties and the methodology itself. There is, however, a difference in behaviour between the two problem solving group incentive types. Regardless of incentives, it is clear that some groups performed better than others. Some groups fell into more blind allies, needed more card exchanges to reach the solution, and took longer to solve the problem. In this section, the relationship between the overall group problem solving process and the overall performance of groups are evaluated. Do groups that perform better show more direct solution paths? Rather than testing the incentive hypothesis, in this section, the relationship between process and performance is evaluated. A few of the important aspects that indicated a difference in behaviour pattern previous, such as solution predictions (code 6 from **Chapter 3.7**), the SD of the time of card exchanges (from **Chapter 4.1.1.3)**, and the number of directional reversals (from **Chapter 4.2**), were tested to see if there was a correlation between these factors and overall ranked performance.

4.3.1 Ranking

Problem solving groups were analyzed by ranking the performance behaviours of each group. Groups were scored by first looking at the number of blind alleys that they fell into. Since many groups fell into the same number of blind alleys, groups were then ranked by the number of exchanges they made. Lastly, groups were then ranked in terms of the time they took to complete the experiment. Therefore, the best performing group fell into the least number of blind alleys, had the least amount of card exchanges (i.e. 12, the minimum number of card exchanges needed to reach the solution), and had the shortest problem solving time.

The scoring system used to rank the groups can be seen in **Table 15.** This table shows the number of blind alleys groups fell into, the number of card exchanges they made, and the time it took them to complete the problem. Dividing these 24 groups into the 12 best performing groups and the 12 worst performing groups shows that the majority of the best performing groups were individual incentive groups (8 of 12), and the majority of the worst performing groups were group incentive groups (8 of 12).

Rank	Incentive Type	Blind Alleys	Card Exchanges	Time (sec)
1	Individual	0	12	316
2	Individual	0	12	408
3	Individual	0	12	416
4	Individual	0	12	528
5	Individual	0	14	1254
6	Individual	0	17	543
7	Group	1	30	554
8	Group	1	42	589
9	Individual	2	16	350
10	Group	2	18	275
11	Individual	2	18	307
12	Group	2	20	531
13	Group	2	20	548
14	Group	2	20	783
15	Individual	2	20	870
16	Group	2	23	676
17	Individual	2	24	707
18	Group	2	28	746
19	Individual	2	28	877
20	Group	2	36	612
21	Group	2	40	682
22	Individual	2	40	1409
23	Group	6	64	1163
24	Group	8	60	1523

Table 15. Ranking score of best to worst performing groups (based on blind alleys, card exchanges, and time to complete the experiment).

Although the majority of the best performing groups were individual incentive groups, and the majority of the worst performing groups were group incentive groups, both types of groups can be seen across the entire ranking. Perhaps larger differences between group types would show if there were a larger number of groups that were tested in the experiment. However, ranking the groups from best to worst performing allowed for a comparison of the overall difference in behaviours.

4.3.2 Correlations

The ranking of group performance was correlated with indicators of groups problem solving behaviour. First, the time range of groups solution predictions (i.e. code 6 from the thematic coding scheme). Second, the SD of the time of card exchanges, and third, the number of directional reversals in the solution path. If the correlations are strong enough, then this might exemplify how behaviour and performance are related.

In **Chapter 3.7**, codes 6, 7 and 8, were used when groups made predictions of solution categories, proposed solution moves, or made statements that they possessed a solution. When looking at the graphs in order from best performing to worst performing, it became apparent that they appeared to have a less organized problem solving paths, and each code appeared throughout the entire experiment. Code 6, the solution prediction code, was important to appear first within the experimental timeline, as this would indicate that groups are carefully predicting solutions before making moves. From **Chapter 3.7,** the results indicated that individual incentive groups had a smaller time range for code 6, and the average at which code 6 appeared throughout the experimental timeline was smaller, indicating that it appeared more frequently at the beginning of the experiment. This therefore shows how individual incentive groups make more calculated moves, and take a more direct solution path. From these results, it was predicted that as a group's performance ranking increased (i.e. their performance decreased), the larger the time range of code 6 (solution predictions) would be. The results of the Pearson correlation showed that there was a positive correlation ($r=0.68$) between the group ranking and the time range of code 6. That is, as a group's performance decreases, the time range of which code 6 appears increases. If code 6 appears throughout the entire experimental timeline, these groups are making solution predictions more frequently than they need to. This ultimately suggests that groups are confused, and are making less calculated moves to reach the solution.

In **Chapter 4.1.1.3**, the SD of the time where groups exchanged cards was compared between group incentive types. It was found that individual incentive groups make their card exchanges in a more narrow range of a time, rather than throughout the entire experiment. Similar to the results of the code 6 time range, this indicates that individual incentive groups are making exchanges in a calculated manner. They are first making solution predictions, and then exchanging cards once they are sure of their solution and moves. Group incentive groups engaged in opposite behaviour. They exchanged cards throughout a larger portion of their experimental timeline, which indicates that they were making more random moves, were more willing to trade cards, and were perhaps more confused of a solution. To explore whether the SD of card exchanges was also related to group performance rankings, a Pearson correlation was calculated. The results of the Pearson correlation showed that there was a positive correlation ($r=0.80$) between the group ranking and the SD of the times when cards were exchanged. This shows that as group performance decreased, cards were exchanged across an increased time-span of the experiment. This suggests that groups that trade throughout the experiment, or in other words, make solution moves, are also more likely to perform worse.

In **Chapter 4.2** the number of directional changes in a group's solution path were calculated. The solution paths were organized in terms of best to worst performing groups, as it was apparent that as groups performed worse, the more directional changes were present. To capture the degree of difficulty that groups are experiencing when they are changing directions in their solution paths more frequently, a Pearson correlation was calculated. The results of the Pearson correlation showed that there was a positive correlation ($r=0.69$) between the number of times that a group changed directions in their solution path, and the group's performance ranking. This means that when a group performs worse, they will change directions more frequently from being correct to incorrect (or vice versa). This shows that groups that are performing worse are also jumping back and forth from being correct to incorrect throughout the experiment.

Calculating the correlations between groups performance and their solution predictions, card exchange SD's, and the directionality of their solution paths shows that group performance is related to each of these factors. From this study, it is known that individual incentive groups make more calculated moves by making solution predictions first, then exchange cards. This ultimately leads them to make fewer errors. Through the analysis of group rankings, it is also known that making more calculated moves and behaving in this manner is related to groups performing better.

4.4 Summary

In this chapter, the other quantitative results pertaining to the overall experiment and additional tests done alongside thematic coding were reported. In the first section of the chapter, the problem solving times and card exchanges of each group incentive type were re-calculated from Chen's (2010) experiment, and found to be significantly different between group types ($p \leq 0.1$). The standard deviation of the timing of card exchanges was also found to be significantly different between group incentive types ($p \leq 0.1$), with individual incentive groups having a more narrow time range of when they exchanged cards. Additional tests that went alongside the memory code and uncertainty code were also reported. It was found that group incentive groups had a significantly larger ($p \leq 0.1$) amount of category label word repetitions compared to individual incentive groups. However, there was no significant difference ($p > 0.1$) found between group types when calculating the time between when participants had the solution and when they stated they were done the experiment. This was determined to be due to the lack of extra time given after collecting a solution to groups who took longer overall. In the second part of the chapter, the additional test comparing the solution paths that the different group types took were reported. Item and category words were scored as being correct or incorrect, and a moving average was graphed. The number of directional changes of this graph was then compared between group incentive types, and individual incentive groups were found to have significantly less directional changes ($p \leq 0.1$), indicating that they took a more direct path to the solution. In the last section of the chapter, the ranking of groups based on performance was discussed. Groups were ranked based on blind alleys, card exchanges, and experimental time. Although both types of incentive groups were across all rankings, the majority of best performing groups were individual incentive groups, and the majority of worst performing groups were group incentive groups. Better performing groups were correlated with having a narrower time range of when they predict solutions, a smaller SD of the time that they make card exchanges, and fewer directional changes in their solution path.

Chapter 5: Discussion

From Chen's (2010) experiment, it is known that individual incentive groups and group incentive groups both performed equally. According to Chen, this meant that they correctly solved the problem, and had no significant differences in the amount of time they spent solving the problem. However, differences emerged in the amount of card exchanges that groups made, the number of blind alleys they fell into, and the difference between their LIB reversals, or in other words, the groups' perception of whether they were subjectively correct versus being objectively correct. Chen (2010) knew that there were behavioural differences between these two group types, but did not know how they differed cognitively, socially, or their problem solving processes (i.e. how they moved from the initial state of the problem to the goal state). In this experiment, the effects of group incentives on group problem solving processes and paths were investigated. This was done by using the data from Chen's (2010) experiment and conducting multiple types of analyses on it. The results of the data indicated that individual incentive groups solved problems more directly, and made more calculated moves in order to avoid the added risk that their incentive imposed. Group incentive groups were willing to explore more of the problem space by making random moves, but were ultimately more confused and less direct in their problem solving paths.

In this section, the summary of the results of this study, as well as the interpretation of these results, are reported. Then, limitations and future works are discussed.

5.1 Summary of Results

5.1.1. Summary of Thematic Coding Scheme Results

In the thematic coding scheme, codes were created to test the hypothesis that individual incentive groups make more calculated moves, understand the problem structure better, share less information, and take a more direct solution path. Code frequency was compared between group incentive types. As part of testing information processing between group incentive types, a memory code was used, but was unfortunately not used by both group types very often overall. There were no significant differences found on the memory code. For problem structure codes, the same issue persisted when testing for awareness of blind alleys and restructuring, however codes for general problem structure awareness appeared more frequently. Significant differences were only found when standardized for time, as individual incentive groups were found to have more general awareness codes compared to group incentive groups, confirming the hypothesis. This remained true when all three types of codes were combined. When testing for differences on the information sharing code, a significant difference was only found in the code used when group participants gave information, not when group participants asked for information. It was hypothesized that individual incentive groups would be less likely to share information, and therefore have fewer codes for both asking and giving information. The results confirmed one of the hypotheses, as individual incentive groups were found to have significantly fewer codes for giving information compared to group incentive groups. When testing for communication differences between groups, it was found that individual incentive groups had significantly fewer instances of group members speaking over one another compared to group incentive groups. The exploration codes unfortunately did not appear frequently enough in both types of groups. However, individual incentive groups had significantly less frequent codes for indicating that they were willing to explore the problem space by making random moves compared to group incentive groups. There was no significant difference found between unwillingness to explore the problem space, but this code was found to only be present after a group member requested to explore randomly. The code for uncertainty revealed that there was no significant difference between group incentive types, but the code did not appear in all group transcripts. Lastly, the solution path was tested in the thematic coding scheme by incorporating codes used when groups made solution predictions, solution moves, and solution statements. The frequency of each of these codes were not significantly different between group incentive type, except for standardized solution statements. This might due to the fact that the task structure of the problem involves a minimum number of solution predictions, solution moves and solution statements. Participants must cooperate and share a minimum amount of information, and make moves. When graphing the instances in which these codes appeared, it became apparent that as groups performed worse (entered more blind alleys), the graphs representing each of these codes were less organized and each code appeared throughout the entire experimental timeline. The time range of each of these codes were therefore calculated to test whether this phenomenon was true. It was found that there was a significant difference for the time range in which solution prediction, solution moves, and solution statement codes appeared. Individual incentive groups had a more narrow time range, and an overall smaller code mean for each of these codes. This indicates that individual incentive groups are more organized in their solution paths. First, they make solution predictions, then once they believe they know the correct solution, they make trades. After the exchange cards, they state and confirm their solutions. Overall, this shows that their organized problem solving process is related to their better performance.

5.1.2. Summary of Other Results

In this study, the problem solving time and card exchanges were calculated differently compared to Chen's (2010) study, but still showed the same results. Individual incentive groups exchanged cards less frequently compared to group incentive groups, but both incentive groups spent a similar amount of time solving the problem. Individual incentive groups were also found to have a significantly smaller standard deviation of the time in which they exchanged cards. This might show that individual incentive groups only make card exchanges when they know that they will reach a solution. Individual incentive groups are more hesitant to give away cards, and may therefore choose to wait until they know all of their moves before they make them. To confirm this prediction, an additional analysis was conducted on the solution path. Item words and category labels were assigned either a 0, if incorrect, or 1, if correct, and then graphed by a moving average. The frequency of directional changes were then counted for each group type, and it was found that individual incentive groups had significantly less directional changes in their solution path. This meant that they did not go from being correct, to incorrect, or vice versa, numerous times, but rather were on a more consistent path. This confirms the predictions made about individual incentive groups behaviour compared to group incentive groups behaviours while problem solving. Lastly, noticeable differences between group behaviours also appeared when looking at groups in terms of performance. Groups were ranked by performance, which was done by first assessing the number of blind alleys they entered, then the number of cards they exchanged, then by the time they took to solve the problem. Group rankings revealed that the majority of the top ranking groups were individual incentive groups, while the majority of the lower ranking groups were group incentive groups. The relationship between group rankings and other behavioural factors such as solution prediction, SD's of card exchanges, and directional changes in the solution path, were calculated. A Pearson correlation revealed that group rankings were correlated with each of these factors, meaning that as groups performed worse, they had a larger time range in which they made solution predictions, had larger SD's, and had more directional changes.

5.1.3. Interpreting the Results

Adding incentives into group scenarios either creates, or takes away, risk. In individual incentive groups, the incentive given to each individual creates a conflict between the group members. Although the task itself requires cooperation, since information must be shared and cards must be exchanged to reach a solution, individuals can be left without the possibility of collecting a solution if other members end the experiment early. For example, it is possible for one member of the group to collect a solution, and then state that they are finished, leaving the other three participants without the ability to exchange with that individual. This is especially problematic if individual incentive groups collect blind alley categories. If two group members collect the two blind alley categories, which are more attractive since they are comprised of four similar items rather than three similar items and one different item, then this leaves the other two participants without a solution. Group members in the individual incentive groups might therefore be more averse to giving away their cards, or giving away information about their cards, since this places them at a greater risk for not being able to collect the correct solution. Individual incentive group members must also have a good understanding of the problem structure itself in order to understand that trading away their cards would leave them at a greater risk. It was therefore hypothesized that individual incentive groups will take a more direct solution path by making more calculated moves, in order to avoid the risky nature of being given an individual incentive. This might ultimately affect their performance, as it was known that individual incentive groups make fewer errors when solving the problem.

Problem solving is a critical and necessary skill across many fields, especially in real-world settings where problems can be complex. From this study, it can be concluded that when groups are given different incentives, they behave and perform differently. In this experiment, although both individual incentive groups and group incentive groups were able to solve the complex problem given to them, they behaved differently and had very different solution paths. However, there are aspects of the study where questions still remain. For example, it was difficult to test for memory effects between the different group types. Memory plays an important role in information processing. It is known that individual incentive groups exchange less cards, which might mean that they must hold the information that they have gathered in their heads. It was hypothesized that individual incentive groups would have more struggles with memory, but this was difficult to test as groups did not make frequent comments of memory struggles, nor did they greatly differ in the amount of times they repeated category label words from group incentive groups. It therefore remains unclear whether the minimizing of card exchanges would lead to greater struggles with memory between the group incentive times, which would ultimately indicate a difference in information processing. Another unclear behavioural difference that remains a question was the difference in uncertainty, or confidence in the solution, between groups. The code for uncertainty was unable to reveal much about the differences between group incentive type, and analyzing the time between when groups' had the solution and when they stated they were done was prone to experimenter bias. It was initially predicted that since individual incentive groups would have a greater understanding of the problem structure, and make more calculated moves to avoid risking losing their solution or cards, they would be more certain of their solution compared to group incentive groups. This was unable to be answered by the methodology in this study, and should be investigated in other future works.

The other factors tested in this study such as problem structure awareness, sharing information, communication, exploring the problem space, making solution predictions, discussing solution moves, and stating completed solutions, were consistent with the predictions made. This was also true for the predictions made about the differences in the groups' solution processes and paths (i.e. the way they moved from the initial state of the problem to the goal state). For example, groups significantly varied in their solution path organization (the time when they made predictions, card exchanges, and solution statements, and the directionality of the correctness of their solution path).

Piecing together the results of the thematic coding scheme with the results from the other analyses conducted in **Chapter 4** gives the overall picture that individual incentive groups and group incentive groups behave differently. The way in which groups perceive risk affects their information processing, communication, and the problem solving process. Incentives not only affect group performance (by causing either less or more errors to be made), but also affect the group problem solving process. Having an individual incentive given in a group scenario adds the factor of risk to the dynamic of the group. On the other hand, groups that are given group based incentives create a more relaxed state due to the lack of risk. Group incentive groups are more willing to explore the problem space, share information, and trade cards, but this eventually leads to their confusion and disorganized problem solving behaviours. This can be seen through a multitude of factors, such as memory load, information sharing, problem structure, and more, which have been highlighted by the group problem solving literature.

By investigating the relationship of these factors with the group incentive conditions in this experiment, this study moves the research field forward by providing researchers with the idea of why and how groups behave differently. This ultimately has an effect in the real world, as heterogenous and homogenous groups are often placed in situations where they must cooperate to solve problems. This is especially prevalent in organizational settings, where individuals from different departments must often come together to work on challenging problems. If the effects and processes explored in this study generalize to other problem solving situations, incentives could potentially be used strategically to encourage different problem solving behaviours in different situations. Individual based incentives might be more appropriate in high-risk situations, where errors or deviations from the optimal solution paths are costly. Alternatively, group based incentives may be more appropriate in situations with lower error costs, but where exploring the problem space is necessary in order to generate novel or creative solutions.

5.2 Limitations and Future Work

Although the present study aimed to explore and investigate how incentives affect group problem solving processing and paths, there were still some limitations to the study. The first limitation was the difficulty of capturing the concepts and hypothesis that was intended to be tested. The thematic coding scheme allowed to test social and cognitive factors that contribute to the behaviours observed by groups solving problem solving, but thematic coding in itself is a qualitative test that involves the subjective interpretation of the researcher. The themes that were created from the thematic coding scheme were generated in both an inductive and deductive way. In other words, they were developed by observing the trial videos and carefully detecting common patterns, and they were generated from previous theoretical works in the problem solving literature. These themes are therefore in themselves subjective, and a different researcher may have developed alternative themes, as multiple social and cognitive factors affect problem solving behaviour, and only a select few were tested in this experiment. For example, leadership and the influence that leaders have on discussion was not tested in this experiment. Leadership is, however, an important factor related to group problem solving, and can have an effect on group performance. For the purposes of this study, the themes that were created and observed still gave an overall picture of the processes that groups used while solving problems (e.g. information processing, memory, information sharing, problem structure, exploration, uncertainty, etc.). While thematic coding is a flexible methodology, it can lead to inconsistency and a lack of inter-rater reliability. Unfortunately, due to the lack of time to complete this experiment, an inter-rater reliability check was unable to be performed. In a future follow-up study, additional researchers should be asked to generate themes. Common themes generated by all researchers could then be coded for. The additional researchers should also code the transcripts for each of the themes that were agreed upon, to check that all transcripts were coded similarly.

Another limitation of this study was the small number of groups that were tested. In Chen's (2010) experiment, 41 groups were tested, however the experiment included groups given mixed incentives as well as individual and group based incentives. In the current study only individual and group based incentives were used, which reduced the amount of available data. Four experimental group videos were also used as trial videos for the thematic coding scheme, which also reduced the amount of available data. Having only 24 group data available made it difficult to test for significant differences between incentive types. For example, in the thematic coding scheme, not all codes were able to be used for each group. Some group members did not make explicit verbal statements of their struggles for memory, which lead to a small amount of data available for the memory code test. This was also true for other codes, but also for the quantitative tests. Some of the variances were large, but if more groups were able to be tested, this might provide a more accurate picture of the behavioural differences occurring between each group type. In future follow-up studies, more groups should be tested in order to generate a larger data set for statistical testing.

In addition to the lack of groups available to test, analyzing data from a previous study also brought about many limitations. Firstly, some aspects of the study had to be recalculated (card exchanges and time of the experiment) due to the differences in interpreting this data. Secondly, new themes and aspects were unable to be tested during the experiment itself. For example, including additional questions in the post-experiment questionnaire would have allowed for a greater insight into what each group member was thinking during the experiment. Questions about memory struggle, uncertainty of the category, willingness to explore by making random card exchanges, and more could be asked of each participant. Having this additional data would confirm the outcomes found in the thematic coding scheme analysis. For example, in the questionnaire used by Chen (2010), participants were asked which aspect of the problem them found most difficult. Some participants wrote about the difficulties that occurred when the group collected a blind alley category. In the experiment itself, the participants did not make explicit inferences that they were aware that the blind alley category existed, which was therefore not captured in the thematic coding scheme. However, participants were clearly aware of the blind alley being present if they wrote about it in the post-experimental questionnaire. Explicitly asking questions about these important factors in a post-experimental questionnaire would be a valuable addition in a future follow-up study.

From the results of this study, it was found that group incentive groups explored more of the problem space, and were willing to make random trades in order to do so. Perhaps this might stem from their confusion on how to solve the problem, the ease of trading cards in order to process information versus keeping items in their memory, or from the freedom that the group-based incentive provides, or a combination of these. These factors are each related to one another, but the outcome of group incentive groups is that also they are able to reach a solution, they do so by making many errors. This can still be beneficial when translating these results into a real-world scenario. For example, in an organizational setting, a group may be created for the sole basis of innovation. Their tasks could be to solve a problem, but they could do so by creating and developing something new. A group based incentive might work best in this type of scenario because exploration of the problem space is encouraged, and errors along the way would not harm the overall result. However, in order to confirm this, the effects of incentives on groups solving ill-structured problems should be conducted. Ill-structured problems are problems that do not have a unique and specific solution, but are instead open-ended. Future work should be done to test this concept in order to generalize results in a real-world scenario.

5.3 Concluding Remarks

Throughout the historical research done on problem solving, it has always been thought that groups outperform individuals (Kerr & Tindale, 2004). Researchers suggest that this might be due to the additional access to knowledge, diverse skills, the development of new ideas, and a greater quantity of ideas (Milliken et al., 2003) that comes about with having more individuals working cooperatively on the same problem. However, from studying how groups that are tasked with solving complex problems, the opposite may be true. Chen (2010) found that although group incentive groups and individual incentive groups were able to solve a complex problem, individual incentive groups made fewer errors. In this study, it was found that giving groups individual based incentives created a problem solving process with fewer errors, more calculated moves, and more direct problem solving path. This study's results provide new insights into the effects of incentives on group problem solving, and the interaction between incentives and problem structures.

Prior research suggested that individual incentives reduce cooperation and information processing in problem solving groups. The results found in this study suggest that different incentives may change how groups cooperate and process information to solve complex problems. In general, our findings suggest that groups may be equally successful at solving complex problems under either individual or group incentives, but they adopt different problem solving strategies and follow different paths to reach solutions. These strategies include processing information differently, understanding the problem structure differently, exploring different amounts of the problem space, communicating differently, and being more or less certain of the solution. Groups predict solutions, make solution moves, and state that they have a solution at different rates. In a complicated problem, there are many paths that groups can take to reach a solution. Different incentives encourage a different type of path, but, the variability between groups are still high. Groups each take their own approach and logic to solve a problem, and more work is still needed to be done to explore group problem solving.

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