Facilitated Rule Discovery in Wason's 2-4-6 Task: The Role of Negative Triples

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Abstract

One key paradigm that has been used to investigate hypothesis-testing behaviour is Wason's (1960) 2-4-6 task. This exists in two main forms: The standard version requires participants to induce a single rule, whilst the logically identical Dual Goal (DG) version, introduced by Tweney et al. (1980), asks participants to discover two related rules. In the standard version success rates of 20% are typically reported, whereas DG instructions increase solution rates to over 60%. One hypothesized explanation for this facilitated effect is the Goal Complementarity Theory (Wharton, Cheng & Wickens, 1993), which proposes that facilitated performance is mainly attributable to the complementary nature of the two unknown rules in the DG task. The present study investigated this theory by manipulating the to-be-discovered rules in order to produce both complementary and non-complementary DG versions of the task. Results did not lend support to the Goal Complementarity Theory. However, a close analysis of the triples generated by participants led to the formation of a new account of the facilitatory effect of DG instructions that centred on the role played by negative triples (and especially descending ones) in promoting task success.

Introduction

Hypothesis testing can be viewed as a fundamental mode of mental functioning that is, for example, vital for the development of effective language skills (e.g., Poletiek, 2001), important for everyday problem-solving and decision making activity (e.g., Manktelow, 1999), and critical for expert reasoning in domains such as scientific discovery (e.g., Klahr, 2000). Given its central importance, hypothesis-testing behaviour has long been of considerable interest to psychologists and cognitive scientists alike. One important experimental paradigm that has been employed in studying people's hypothesis-testing is Wason's (1960, 1966) 2-4-6 task (see also Johnson-Laird & Wason, 1970). In the standard form of the 2-4-6 task participants are asked to discover a rule, known to the experimenter, that generates sequences of three numbers (referred to as triples). The experimenter provides an example triple of 2-4-6 as being one that fits the rule. Participants are then asked to generate further triples that the experimenter classifies as either fitting or not fitting the to-be-discovered rule. Participants are encouraged to produce triples until they reach a point where they are confident that they know the rule, at which point they announce it. The to-be discovered rule is 'ascending triples'.

Despite the apparent simplicity of the 2-4-6 task actual success rates for first time announcements are very low, with frequencies of around 20% commonly being reported (e.g., Tukey, 1986; Wason, 1960; Wharton, Cheng & Wickens, 1993). Incorrect announcements are typically more restricted versions of the rule such as 'numbers increasing with intervals of two' (Wason, 1960). Wetherick (1962) has argued that the initial exemplar of 2-4-6 leads participants into forming such overly restrictive hypotheses. Recent work by Van der Henst, Rossi and Schroyens (2002) also supports this view, and invokes a 'relevance' explanation for this effect.

Although Van der Henst et al.'s research is timely and informative, it focuses only on the question of why overly-restricted hypotheses are formed in the first place, and therefore remains silent on the equally important issue of why participants fail to test such initial overly-restrictive hypotheses using the Popperian ideal of falsification. Indeed, apparently lured by the plausibility of their initial hypotheses, participants are typically observed to produce many test triples that conform to it, for example, ones such as 6-8-10, 12-14-16, 20-22-24, and the like, in the case where the initial hypothesis of 'numbers increasing with intervals of two' is formed. As these triples are a subset of the true rule, they always receive positive feedback, thus increasing the participant's confidence in the correctness of their working hypothesis. It is clear, then, that to discover the true rule a participant needs to change their strategy of producing positive instances of their working hypothesis so as to discover that it is overly limited (i.e., that whilst it may be a *sufficient* rule to account for the available evidence it is not a *necessary* one).

Dual-Goal Instructions

Although reported success rates on the 2-4-6 task are typically low, one reliable method of increasing the frequency of correct initial rule announcements is to use what has become known as the Dual Goal (DG) paradigm. Introduced by Tweney, Doherty, Worner, Pliske, Mynatt, Gross and Arkkelin (1980), this is a formally equivalent version of the task in which participants are asked to find two rules, one called DAX, and the other MED. The DAX rule is the usual 'any ascending numbers' rule, while the MED rule is 'all other triples'. The participants are presented with an exemplar DAX triple of 2-4-6, and feedback is given in the form of either DAX or MED. Using this modified version of the task success rates increase dramatically; Tweney et al. (1980) reported a success rate of 60% for first rule announcements, and this finding has been replicated many times (e.g. Farris & Revlin 1989a, 1989b; Tukey, 1986; Wharton et al., 1993). Although the facilitatory effect of DG instructions is well documented there is, to date, little agreement as to the cause of enhanced rule discovery. Tweney et al. (1980) themselves felt unable to offer a theoretical account beyond noting their belief that the explanation lay in the relationship between the way that participants conceptualized the problem, and the way that empirical evidence was related to that conceptualization.

Wharton et al. (1993) proposed two possible accounts for the effect. The first, which they labeled the *Information-Quantity Theory*, derived from observations that: (1) solvers given Single Goal (SG) instructions generate more triples than non-solvers (Farris & Revlin, 1989; Wason 1960); and (2) DG instructions lead to the generation of more triples before initial rule announcement than do SG instructions (Gorman, Stafford & Gorman, 1987). Wharton et al. claimed to have undermined this theory themselves since they controlled for the minimum number of triples that participants could generate before announcing the rule and still found a DG solution advantage over individuals receiving SG instructions. However, Wharton et al. only demanded the production of a *minimum* number of triples, and participants in their DG condition were actually seen to generate reliably more triples than those in the SG condition before making a first rule announcement. Wharton et al.'s manipulation cannot, therefore, be construed as a strict test of the Information Quantity Theory of DG facilitation.

A second explanation of DG facilitation proposed by Wharton et al. (1980) is their own *Goal-Complementarity Theory*. According to this account, the beneficial effect of DG instructions can be attributed to a combination of the complementary nature of the DAX and MED rules, and the tendency for people to adopt a *positive test strategy* (Klayman & Ha, 1987) that leads to the generation of triples that match the participant's current hypothesis. Wharton et al. thus propose that the initial DAX exemplar of 2-4-6 induces the participant to hypothesize a restricted rule for DAX such as 'numbers ascending by two' (cf. Wetherick, 1962) that they then test with further positive triples. However the requirement to search for a second, MED, rule forces the participant to generate a second hypothesis for MED triples (e.g., 'numbers ascending by other than two') that they also test using the same positive test strategy (e.g., proposing a triple such as 2-3-10). Such a test of MED would result in unexpected DAX feedback, that, in turn, would cause the participant to vary their DAX hypothesis to accommodate this new information. The cycle would be repeated until the participant had produced appropriate rules for both DAX and MED.

It is noteworthy that the Goal-Complementarity Theory assumes that success on the task is attributable to the generation of triples (like 2-4-10) which Vallée-Tourangeau, Austin and Rankin (1995) refer to as being *variable positives* (or 'posvars'). These posvars are ascending triples but ones in which numbers do not increase by equal increments. Contrary to the critical role that posvars should play in promoting DG facilitation, however, a recent study by Gale and Ball (2002) showed that although the production of at least a single posvar was associated with task success, the production of at least a single negative triple showed a far more marked association with correct rule discovery. This latter observation may also link to Wason's (1960) finding that solvers produce a higher ratio of negative triples than non-solvers. It also points to the intriguing possibility that the generation of negative triples may well be more central to DG facilitation effects than posvar production.

Wharton et al. (1993), however, have claimed support for the Goal-Complementarity Theory in a study where they showed that if the complementary nature of the DAX and MED rules is *not* made explicit to participants then DG instructions likewise do *not* lead to facilitated performance. This was the first reported incidence of a failure of DG instructions to improve performance (although it is noteworthy that in the original Tweney et al., 1980, study the relationship between the rules was not made clear and success rates remained high). Vallée-Tourangeau et al. (1995), on the other hand, have claimed to have undermined the Goal-Complementarity Theory in an experiment that manipulated the apparent nature of the relationship between the DAX and MED rules such that they were no longer presented as being complementary to one another. Vallée-Tourangeau et al. demonstrated that high success rates were still evident even when participants were testing such non-complementary DAX and MED rules. It should be noted, however, that although Vallée-Tourangeau et al. told their participants that triples could be DAX, MED, or neither (and, in another condition, DAX, MED, or both), it remained the case that the standard DAX and MED rules were still used. What this means is that unbeknownst to participants, the logical relationship between the two rules actually remained strictly complementary and they never, therefore, received any feedback other than DAX or MED. It could be argued that because the relationship of the rules was not truly manipulated by Vallée-Tourangeau et al., then their methodology contains inherent flaws that may have led to the production of artefactual evidence against Wharton et al.'s (1993) Goal-Complementarity Theory.

Vallée-Tourangeau et al. (1995) have proposed a further theory as to why DG instructions facilitate performance on the 2-4-6 task. They suggest that DG requirements foster a more creative exploration of the triple space as indexed by the *variety* of triples generated by participants, and that it is this sheer breadth of hypotheses tested that leads to success. To test their proposal they formulated a system of codifying both negative and positive triples. As noted earlier, triples receiving positive (DAX) feedback may increase by variable increments (posvars) or by constant increments. There are also eight possible types of triples, termed 'negtypes' by Vallée-Tourangeau et al., that could receive negative (MED) feedback, such as descending triples and identical-number triples. The possible set of eight negative types is captured by the following rules proposed by Vallée-Tourangeau et al.: (1) $a > b > c$; (2) $a = b = c$; (3) $a > b < c$; (4) $a < b > c$; (5) $a = b < c$; (6) $a = b > c$; (7) $a > b = c$; (8) $a < b = c$. Vallée-Tourangeau et al. reported that use of the DG inferential context led to both a greater number of posvars compared to the traditional single goal procedure, and also a greater number of negtypes. Solvers and non-solvers in the two conditions could also be differentiated on these measures.

Although it is useful to have a system for codifying the range of triples generated by participants, the suggestion that a greater variety of triple types is indicative of the range of hypotheses considered was not directly tested by Vallée-Tourangeau et al. (1995). It is also evident that many hypotheses may be entertained that are not centred on the relationship of the numbers to one another, but that are more concerned with properties that the numbers have in common, for example, even numbers, positive or negative numbers, or numbers produced by some arithmetical formula such as those adding to less than 20. As such, whilst Vallée-Tourangeau et al.'s findings may capture important aspects of participants' triple-generation behaviour at a fairly gross level of analysis, the precise relationship between participants' triple-generation activity and their actual working hypotheses during task performance remains elusive.

The present study aimed to investigate further the Goal Complementarity Theory by explicitly manipulating the logical relationship of the DAX and MED rules in the DG paradigm so that these rules were no longer complementary. The Goal-Complementarity Theory would predict that when the two rules lack mutual complementarity then the facilitatory effect of DG instructions should be undermined (Wharton et al., 1993; Vallée-Tourangeau et al., 1995). In addition, the Goal Complementarity Theory would predict that it is the production of at least a single posvar that should be necessary for successful initial rule announcement, rather than production of negative triples. These latter predictions can be tested by analyzing the types of triple generated across conditions. The analysis of triples types also enables an assessment to be made of predictions deriving from Vallée-Tourangeau et al.'s (1995) *Triple-Heterogeneity Theory* to the effect that it is the *variety* of triples tested by participants that is central to success with DG variants of the 2-4-6 task. As a final point, we note that because of the contradictory nature of the evidence surrounding the Information Quantity Theory it was decided to impose a strict control for information quantity by requiring participants in all conditions to generate exactly 10 triples before stating their best guess at the rule (at which stage the experiment terminated).

Method

Participants

Eighty students from sixth-form colleges in Derbyshire took part in the study on a voluntary basis. None had received any teaching relating to reasoning or logic.

Design

An independent-measures design was employed with four conditions: Single Goal (SG), Standard Dual Goal (DG), Dual Goal Three (DG3) in which feedback consisted of DAX, MED, and neither DAX nor MED, and Dual Goal Four (DG4), in which feedback consisted of DAX, MED, neither DAX nor MED, and both DAX and MED. Twenty participants were randomly assigned to each of the four conditions.

Procedure

Participants were tested in groups of four, with each group being read standardized instructions. Participants in the SG group heard instructions referring to a unique rule: *"I have in mind a rule that specifies how to make up sequences of three numbers (triples), and your task* *is to discover this rule"*. Participants then produced 10 triples and received DAX or MED feedback for triples fitting or not fitting the experimenter's rule, respectively. After the 10 triples participants were asked to write down their best guess at the rule. Instructions for all other conditions asked participants to discover two rules, one called DAX and one called MED. The DAX rule in each of these conditions was 'ascending numbers'. For the standard DG condition the MED rule was 'any other triple', while for the DG3 condition the MED rule was 'descending numbers', and for the DG4 condition the MED rule was 'odd numbers'. Thus in the DG3 condition triples could be classified as conforming to the DAX rule, the MED rule or neither, while in the DG4 condition triples could be DAX, MED, neither or both. As in the SG condition, participants were asked to produce exactly ten triples before writing down their best guess at the rules.

Results and Discussion

Solution Success Across Conditions

Table 1 shows the frequency of correct initial rule announcements for the DAX rule in each of the experimental conditions. It is clear that those in the DG4 condition had the greatest difficulty with the task, with correct solutions being offered in only 15% of cases. In contrast, the frequency of correct solvers in the DG3 condition is comparable (and indeed marginally superior) to that of the standard DG condition, whilst the frequency of correct solvers in the SG condition is lower than that seen in the DG and DG3 conditions. A chi square analysis showed these differences to be highly significant, $\chi2 = 18.24$, df = 3, $p < .001$. The high levels of solution success in the non-complementary' DG3 condition appear at odds with the Wharton et al.'s (1993) Goal Complementarity Theory.

Table 1: Frequency of correct DAX rule announcements.

Condition	N	Solver	Non-solver
SG	20	7	13
DG	20	13	7
DG3	20	15	5
DG4	20	3	17

Triple Types Across Conditions

Vallée-Tourangeau et al.'s (1995) Triple-Heterogeneity Theory claims that DG instructions facilitate performance on the 2-4-6 task by fostering the generation of a wider range of hypotheses as indexed by the variety of triples produced. Vallée-Tourangeau et al. argue that triple variety can be quantified in terms of the number of triples receiving *negative feedback*, the number of *posvars* generated, and the number of *negtypes* produced. The mean scores by condition on each these indices are presented in Table 2. Wharton et al.'s Goal Complementarity Theory also assumes a critical association between posvar generation and DG instructions. To examine such predictions we applied a series of one-way, between-participants analysis of variance (ANOVA) tests to the three indices of triple variety. A significant effect of condition was found for the number of triples receiving negative feedback, $F(3,76) = 3.61$, $p < .05$. Post hoc Bonferroni tests indicated that more triples received negative feedback in the DG condition than in the SG condition ($p < .05$), however, there were no differences between the other conditions. The ANOVAs revealed no effect of condition on either the negtype or the posvar measures. These latter findings are, again, contrary to the Goal-Complementarity and Triple-Heterogeneity Theories.

Triple Type and Solution Success

The mean number of negative triples produced by solvers was 4.41 (SD = 1.99) and by non-solvers was 2.22 (SD = 2.24). This difference was highly reliable, $t(78) = 5.12$, $p < .001$. A significant difference was also found in the mean number of negtypes produced by solvers (2.22, SD = 1.23) and non-solvers (1.41, SD = 1.37), $t(78) = 3.11$, $p < .01$, but not in the mean number of posvars produced by solvers (1.8, SD = 1.81) and non-solvers (2.02, SD = 1.93), $t(78) = 0.53$, $p > .05$.

Gale and Ball (2002) demonstrated that the production of at least a *single* triple receiving negative feedback ('negpres') was more closely associated with success on the 2-4-6 task than the production of a *single* posvar ('posvarpres'). To clarify the relative influence of negpres and posvarpres on task success we modeled the present dataset using logistic regression. An initial model in which the predictor variable of negpres (yes/no) was regressed onto solution success (solver/non-solver) was highly significant, B = 3.05, Wald = 8.35, $p < .001$, demonstrating that the presence of at least one negative triple was closely associated with task success. A second model regressing posvarpres onto success failed to reach significance, B = .512, Wald = 1.16, $p > .05$, supporting the view (Gale & Ball, 2002) that the production of posvar triples may have a limited link to successful rule discovery on the 2-4-6 task.

Since the production of negative triples appeared to have such a strong association with task success we decided to examine what specific property of negative triples might underpin this success. It became clear upon scrutinizing the negative triples generated by participants that the great majority of these were 'descending' in nature, and that most other types of negative triples were generated only very occasionally. For this reason we collapsed all negative triples apart from descending ones of the form $a > b > c$ into a single

Table 2: Mean number of triple types produced by condition, with standard deviations in parentheses.

	Condition			
	SG	DG	DG3	DG4
Negative feedback	2.05 (2.31)	4.05 (1.90)	3.75 (2.31)	2.50 (2.52)
Negtypes	1.05 (1.15)	2.00 (1.30)	1.95 (1.05)	1.55 (1.57)
Posvars	1.15 (1.81)	1.80 (1.61)	1.75 (2.34)	2.85 (1.93)

pool. We then compared the effect of producing versus not producing at least one descending triple on task success. Logistic regression showed that participants generating a descending triple were twelve times more likely to solve the task than those not producing such a triple. This effect was highly reliable, B =2.55, Wald = 14.24, $p < .001$. Production versus non-production of at least one other type of negative triple was not predictive of success, B = .427, Wald = .89, $p > .05$.

Path Analysis

Our final exploration of the dataset involved conducting a path analysis to establish whether producing versus not producing at least one descending triple played a *mediating* role in task success (i.e., intervening between the type of task instruction and task performance at initial rule announcement). Because quantitative logic does not work appropriately with logistic regression, it was necessary to use linear regression for the analyses. We acknowledge that this is not ideal given the dichotomous nature of the relevant variables, but have included comparisons of obtained *p* values for logistic and linear regressions (Table 3) to illustrate the high level of comparability of the calculations, and to thereby go some way toward validating the use of the linear-regression procedure with the present dataset. It should also be noted that examination of the data revealed little difference in triple-generation behaviour between the standard DG and the DG3 conditions, and for this reason these conditions were collapsed for the path analysis. In addition, data for participants in the DG4 condition were excluded from this analysis as so few people in this condition solved the task, and examination of their protocols suggested they had found the task so difficult that they had generated triples without employing any discernible strategy.

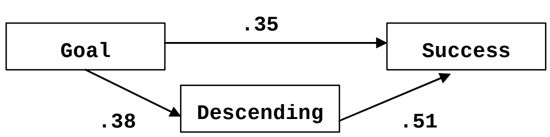

Figure 1: Path diagram showing the mediating role of producing at least one descending triple on task success.

Figure 1 shows the path diagram obtained when the mediating role of the production of at least one descending triple was examined to assess its effect on task success. A Sobel test showed this mediating effect to be significant, Goodman (1) = 2.62, $p < .01$.

General Discussion

Our results appear to challenge Wharton et al.'s (1983) Goal-Complementarity Theory of DG facilitation in two respects. First, when the relationship between DAX and MED rules is manipulated such that they are no longer logically complementary (i.e., triples can be produced that fit neither rule) then performance on the DG version does not suffer. This contradicts the assumption of the Goal Complementarity Theory that it is the complementary nature of the DAX and MED rules that is the crucial factor underpinning facilitated performance on DG tasks. Second, the Goal Complementarity Theory also assumes that it is the production of posvars that promotes insightful rule discovery. The results from our logistic regression analysis demonstrate that this is not the case. Our path analysis likewise reveals that it is production of at least one descending triple that mediates task success.

The results also undermine the Information Quantity Theory since DG instructions led to greater success on the task than SG ones, despite the fact that all participants generated the same number of triples. We also challenge the Triple Heterogeneity Theory that DG instructions facilitate performance by fostering consideration of a broader range of hypotheses (as indexed by the greater variety of triples produced), since the only significant difference we detected on the measures of triple heterogeneity across conditions was the number of triples receiving negative feedback. It cannot readily be argued that this is a true measure of heterogeneity as it really only records the number, and not the range, of negative triples generated.

We can, however, make some new and positive observations as to the possible causal mechanism of success on the 2-4-6 task. Our data indicate that it is the production of at least a *single negative triple* that leads to task success. From this we can assume that there must be some property inherent in a negative triple that

Table 3: Comparison of *p* values from logistic and linear regressions associated with the path analysis.

Variables in the regression analysis		Linear Regression	Logistic Regression
Goal regressed onto Descending triple		.009	.004
Goal regressed onto Success		< .001	.012
Descending triple regressed onto Success		< .001	.001
Goal & Descending triple regressed onto Success	*Goal*	.168	.164
	Descending triple	< .001	< .001

Note: Descending triple: present vs. absent; Success: yes vs. no; Goal: SG vs. DG

promotes the formation of a correct DAX hypothesis. We further report that it the production of at least a single *descending* triple that is most closely associated with task success. This observation suggests that the testing of a triple such as 6-4-2 that leads to MED feedback may cause 'descending' to become the salient dimension of MEDness. This, in turn, may promote the realization that 'ascending' is the salient feature of DAXness by the provision of a useful contrast class. This is clearly a novel idea that requires further testing. Future work also needs to clarify why DG instructions lead to the production of negative triples. As Wharton et al. (1993) note, a restricted rule for DAX such as 'numbers ascending by two' may lead to a hypothesis of 'numbers ascending by other than two' for MED, but it not clear why such a hypothesized MED rule will lead to the production of a negative triple. Closer analysis of the protocols produced by participants may be useful in elucidating this issue.

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