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Self-Explanation, Feedback and the Development of Analogical Reasoning Skills: Microgenetic Evidence for a Metacognitive Processing Account

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Abstract

It is generally accepted that providing explanations during a task can facilitate problem solving performance in both adults and children. This paper aims to answer two important questions. First, can current theories of explanation be generalised to children's explanations of self-generated answers? Second, what is the impact of such self-explanation on the development of children's analogical reasoning skills? One-hundred-and-ten six- and seven-year-old children took part in seven sessions of matrix completion trials in one of five conditions: (1) explanation plus feedback; (2) explanation only; (3) feedback only; (4) practice; and (5) control. Analysis revealed that, contrary to existing theory, explanation of self-generated answers is not the most effective way to encourage the development of analogical reasoning. Rather, feedback on response accuracy is necessary for the attainment of heightened levels of performance. Results also indicate that children shift from using surface-level perceptual cues as a basis for their responses to a more sophisticated strategy involving an understanding of deeper-level relational structures. It is argued that these results support a metacognitive processing account of the development of analogical reasoning skills rather than an account emphasising changes in mental representations.

Keywords: Analogical reasoning; self-explanation; feedback; metacognitive processing; strategy development.

Introduction

As part of experimental procedures in developmental research, children are often asked to justify answers they have given on problem-solving tasks to provide a measure of their understanding (e.g., Gentner, 1988; Inhelder & Piaget, 1964; Tolme & Phillips, 2004). These studies, however, frequently fail to consider the impact that explanation requests have on the child's actual problem-solving performance. The limited research that has examined the effect of eliciting explanations on children's performance has typically required participants to explain correct or incorrect answers supplied by someone else such as the experimenter or a puppet (Muldoon, 2004; Pine & Messer, 2000; Siegler, 2002) rather than their own answers.

These latter studies support the view that explanation benefits learning and problem solving. However, such studies involve explanation procedures that are potentially rather different to asking children to explain their *own* responses. The few studies that have examined the consequences of explaining self-generated answers have mostly assessed behaviour in either adolescent or adult populations (e.g., Bielaczyc, Pirolli, & Brown, 1995; Chi, Bassok, Lewis, Reimann, & Glasser, 1989; Chi, deLeeuw, Chiu, & Lavancher, 1994). These studies have revealed an association between self explanation and facilitated learning and problem solving. One exception to this body of work is the research reported by Rittle-Johnson (2004), which examined children's self-explanation with mathematics problems and found beneficial effects. However, the fact that this experiment combined self-explanation requests with task feedback means that we cannot know for sure whether simply asking children to provide self-explanations of their responses aids problems solving. We note, however, that some developmental theorists (e.g. Crowley & Siegler, 1999; Pine & Messer, 2000; Siegler, 2002; Siegler & Svetina, 2002) appear to assume that because explanation of self-generated responses is beneficial for adult learning then such effects should extrapolate to children's learning. There are good reasons, however, for why this might not be the case. For example, children's language skills are not as sophisticated as those of adults, and children may not, therefore, be able to articulate their thoughts as effectively as adults can. Support for these proposals has recently been demonstrated by Cheshire and Lewis (2003) where it was found that asking young children to provide explanations on the Tower of Hanoi task failed to improve performance, whereas a similar explanation requirement is known to facilitate enhanced performance in adults (Berardi-Coletta, Buyer, Dominowski, & Rellinger, 1995).

The aim of the present research was to examine the impact of explanation of self-generated responses on children's development of problem-solving skills in an analogical reasoning paradigm. This is important for two main reasons. First, it allows for an examination of whether or not current theories of explanation can be applied to children's explanations of their own answers. Second, it permits an

investigation of the impact of providing explanations on the actual development of reasoning skills.

Theories of Explanation and Problem Solving

Two main theoretical approaches can be identified that aim to address the impact of explanation on learning and problem solving. The 'metacognitive processing' approach emphasises the notion that asking participants to provide explanations promotes high-level cognitive processing. For example, Berardi-Coletta et al. (1995) propose that when participants are required to give explanations they shift their attention from problem-based features (i.e., goals and rules of the problem) to a processing level (i.e., whereby they consider strategies, make subgoals and evaluate moves). Similarly, Siegler (2002, in press) focuses on the issue of strategy development and suggests that explanation helps children 'to decrease the strength of existing, incorrect ways of thinking' (Siegler, in press, p.40 of ms). The alternative, 'mental representation' account proposes that providing explanations aids the formation of a complete and accurate mental representation of the problem. For example, Newman and Schwartz (1998) suggest that explaining helps learners to fill the gaps in their mental representations of the problem space. Similarly, Chi (2000) believes that explanation helps participants to reorganise their knowledge to augment incomplete 'mental models'. Strikingly similar suggestions have also been forwarded by researchers studying children's problem solving. For example, Pine and Messer (2000) suggest that through providing explanations children are able to combine new information with existing knowledge to gain a more complete representation.

The Development of Analogical Reasoning

It is generally agreed that children's analogical reasoning develops significantly over the first few years of primary school (Halford, 1993; Inhelder & Piaget, 1964; Siegler & Svetina, 2002). There are three main suggestions as to what enables increasingly more sophisticated analogical reasoning. One proposal is that as children learn more about the world they are then able to use that increasing domain knowledge to reason about the relationships between items (e.g., Goswami, 1992, 2002). This account emphasises the role of domain familiarity in the development of analogical reasoning. Children who are reasoning in familiar domains can make correct analogies, whereas children will have problems when they do not understand the relations between items and will then concentrate on surface features (Goswami, 1992, 2002). A second proposal is that it is the occurrence of a 'relational shift' that promotes the development of more sophisticated analogical reasoning (e.g., Gentner & Toupin, 1986; Ratterman & Gentner, 1998). This account claims that children will initially make errors as they rely on perceptual features of stimuli to reach an answer. These errors then decrease with age and experience, as responses are then based on relational cues. A third suggestion is that older children have better analogical reasoning skills because of an increased ability to represent 'multiple dimensions' arising from age-related changes in the capacity of working memory (Halford, 1993).

We note that these three proposals appear to dichotomise on a 'representational' versus 'process' dimension that is very similar to that which characterises alternative accounts of self-explanation phenomena, outlined above. For example, the 'domain knowledge' account proposed by Goswami (1992, 2002) and the 'multiple dimension' proposal of Halford (1993) both emphasise developments in the representational aspects of task-based knowledge. In contrast, Gentner's 'relational-shift' account (e.g., Gentner & Toupin, 1986; Ratterman & Gentner, 1998) is more closely tied to changes in metacognitive processing (e.g., concerning identification and mapping of causal relations).

Recently, Siegler and Svetina (2002) have employed a 'microgenetic' methodology to examine the development of analogical reasoning ability and have provided evidence that is claimed to support Gentner's relational shift hypothesis. The microgenetic method involves intensive testing over a period of developmental change, and provides a rich dataset that can reveal more detail about *how* children's skills develop. The analogical reasoning paradigm that Siegler and Svetina used involved 'matrix completion' (see Figure 1). This entails a participant completing a part-filled grid of items. If the correct item is selected, then the top items should be related in the same way as the bottom items and at the same time the left hand items should be related in the same way as the right hand items. Siegler and Svetina provided children with feedback and asked them to give explanations of the correct answer. They observed that over a period of three weeks of intensive testing children stopped using a dominant incorrect strategy (based on perceptual similarity) and began to implement the correct strategy (based on relations between objects). Siegler and Svetina could not, however, pinpoint what aided children's shift to relational responding. They suggest that it could have been due to explanation *or* feedback *or* both - or even simply a consequence of repeated exposure to the task.

The present experiment aimed to extend Siegler and Svetina's research using an equivalent microgenetic methodology to discover whether self-explanation alone (i.e., without feedback) is sufficient to develop analogical reasoning to the same extent as observed in Siegler and Svetina's study. If existing theories of explanation generalise to children's self-explanation of self-generated answers then it would be predicted that children who are asked to provide explanations would successfully develop their analogical reasoning skills. However, there is some doubt that explanation alone will be enough for children to refine their analogical reasoning skills (e.g., Berardi-Coletta et al. 1995; Cheshire & Lewis, 2003). There is little evidence to suggest that children's explanations will be based on anything other than purely perceptual features of the task. In fact, Gentner (1988) showed that the verbal justifications elicited from children at early stages of cognitive development were typically dominated by the mention of surface features of objects. Therefore, it is predicted that children will need to be given feedback as well as being asked to provide explanations over the training period for them to reach high levels of performance. Unlike most previous research on explanation and problem solving, which has focused on effects arising at a single point in time, our use of the microgenetic method also

affords the advantage of allowing an assessment of the dynamics of strategy change relative to explanation and feedback.

Method

Participants

A total of 110 6- and 7-year-old children took part in this experiment (mean 7:0; range 6:1 to 7:9). Fifty-seven were female and fifty-three were male. The children came from four different schools in rural Lancashire. If children scored above 80% in Session 1 they did not take part in the rest of the experiment as they were considered to have a high level of understanding already.

Design

This experiment involved children taking part in six sessions of training over a three-week period with a seventh follow up session approximately nine weeks later. They were randomly allocated to one of five conditions: (1) Explanation plus feedback; (2) Explanation alone; (3) Feedback alone; (4) Practice; and (5) Control. Children in the four experimental conditions took part in all seven sessions, with the control group only taking part in Sessions 1 and 7. In Sessions 1, 6 and 7 children in all conditions were given the matrices with no experimental manipulation, so performance at these specific times was more comparable. This was to avoid the potential issue that asking children to provide explanations or giving them feedback may only affect performance when they are actually engaged in the given problems.

Materials

A series of matrices were developed based on the stimuli created by Siegler and Svetina (2002). The stimuli were depictions of large, four legged animals, that could change on up to four relational dimensions: colour, size, type and orientation. Stringent controls were applied to the stimuli so that it was not possible for participants to reason based on irrelevant aspects of them. The potential answers were constructed so that there was one correct answer, one response that was an incorrect colour, one an incorrect size, one an incorrect type, one an incorrect orientation and one that was incorrect on all four dimensions. On each trial these potential responses were positioned randomly in a two by three grid (see Figure 1).

Each microgenetic session involved twenty-two matrix trials: twelve that changed on two dimensions, eight that changed on three dimensions and two that changed on all four dimensions. Within each of these subsets the order of trials was randomised. Each child received a different set of matrices in each session; the order in which they received them was randomised. Children were required to select an animal from the array on the right to complete the matrix on the left. The example in Figure 1 is a trial that changes on two dimensions: size changes vertically and colour changes horizontally. The correct answer is the small yellow camel facing right (i.e., the lower left-hand item).

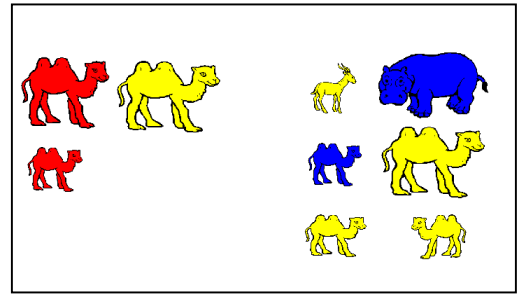


Figure 1: Example of a Matrix Completion Trial

Procedure

Children were presented with twenty-two matrix completion trials in each of the seven sessions. In Session 1 children were introduced to the task and given eight simple practice trials. These trials changed on only one dimension. All children, regardless of condition, were given the same instructions and practice trials. Only Sessions 2-5 included the experimental manipulations. The children who were required to provide explanations were simply asked why they had selected a particular answer on each trial. In the feedback groups children were either told that they had chosen the correct answer or the experimenter indicated which of the potential answers was actually the right one. In the explanation plus feedback group children received the same feedback after they had given an explanation of their own answer. Children in the practice group were given neither explanation nor feedback. A common criticism of experiments that examine explanation is that control groups often spend much less time involved with the task than groups asked to provide explanations (see Newman & Schwartz, 1998). Therefore, in the present study measures were taken to reduce the discrepancy between conditions in the amount of time children spent engaged on the task. For example, in the practice group children were asked questions about the various dimensions of the stimuli to keep their attention focussed on a task-related activity. An example of a question that the child might be asked was “How many blue animals are there?”

Results

Correct Answers

Initial analyses of the number of correct answers that children selected focused on the two end-points of the training procedure (i.e., Session 1 vs. Session 7). This allowed for a clear-cut examination of quantitative improvements in analogical reasoning skill over time (see Figure 2). Analysis of variance revealed that there was a significant increase in correct responses between Sessions 1 and 7, $F(1, 87) = 87.63$, $p < .001$, and a significant interaction between Group and Session, $F(4, 87) = 3.49$, $p = .01$. Simple main effects analyses revealed that there was no significant difference between children in Session 1 ($p = .95$), indicating a common level of initial performance. The improvement in performance

over the sessions was reliable in all conditions ($ps < .02$) apart from the control group ($p = .07$). There was a significant main effect of group at Session 7 ($p = .01$). However, post hoc analyses indicated that the only reliable difference was between the explanation plus feedback and the control groups ($p = .02$).

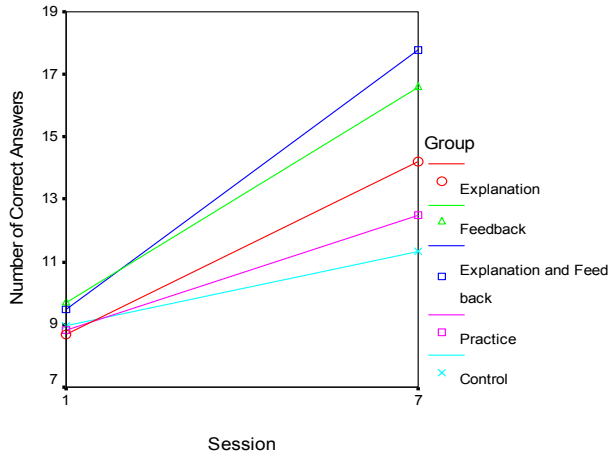


Figure 2: The improvement in children’s performance between Session 1 and Session 7

To analyse the development of analogical reasoning skills in more detail, the number of correct answers was also examined on a per-session basis. Figure 3 illustrates the performance of children in each condition. It is important to reiterate that the explanation and feedback requirements only pertained in Sessions 2-5. In addition, Session 7 was carried out approximately nine weeks after Session 6.

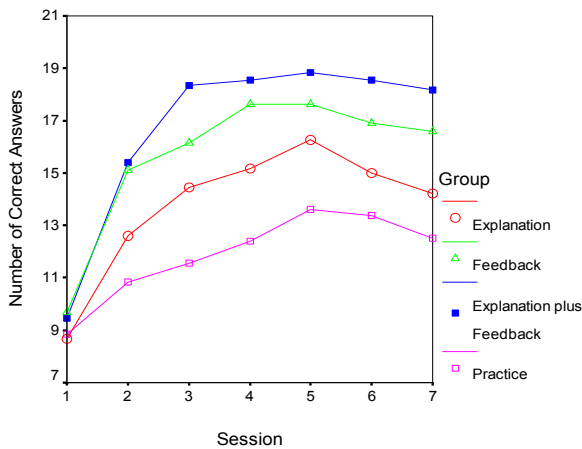


Figure 3: The improvement in children’s performance over seven sessions. (Note: The control condition have not been included as they only took part in conditions 1 and 7)

The repeated measures ANOVA confirmed that children’s performance improved over the seven sessions, $F(6, 414) = 60.96, p < .01$. There was also a main effect of Group, $F(3, 69) = 2.77, p = .048$, and an interaction between Session and Group, $F(18, 414) = 1.81, p = .02$. Post hoc analyses

indicated a significant difference between the explanation plus feedback group and the practice group ($p = .046$).

These data are complex and although there is a clear trend in performance, these traditional methods of data analyses were not powerful enough to completely unravel the findings. Current analyses are exploring the data in terms of Binomial Logistic Models which will be able to model the group differences and also take into consideration individual children’s performance. However, it is still possible to use ANOVA to examine two specific aspects of the data. First, there was a significant decrease in correct answers between Session 5 and Session 6, $F(1, 69) = 4.83, p = .03$. However, there was no main effect of Group ($p = .08$) nor an interaction between Session and Group ($p = .54$). Post hoc tests revealed that the only significant decline in performance was that of the explanation group $F(1, 17) = 5.98, p = .03$. It seems therefore, that the main effects of explanation without feedback come at the time it is elicited. Second, there was no significant decline in performance in any group between Sessions 6 and 7 ($ps > .06$). This indicates that the level of learning that participants had achieved did not significantly decline over a substantial period of time.

Duplicate Errors

Children often incorrectly selected an answer which was a duplicate of an item in the matrix (e.g., the large yellow camel facing right in the example in Figure 1). Duplicate responding is typical in young children (e.g., Ratterman & Gentner, 1998; Siegler & Svetina, 2002) who are considered to rely on perceptual features of stimuli to select an answer. Figure 4 illustrates the average number of duplicate errors made by each group over the seven sessions.

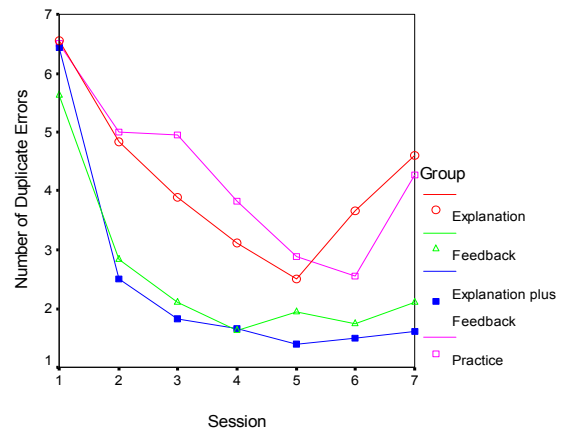


Figure 4: The number of duplicate errors children made over seven sessions. (Note: The control condition have not been included as they only took part in Conditions 1 and 7)

Duplicate errors were seen to decline significantly over the first five sessions, $F(4, 256) = 34.67, p < .01$. There was no main effect of Group ($p = .13$) nor an interaction between Session and Group ($p = .44$). It is interesting to note that after Session 5 the level of duplicate errors that children made in both the explanation and practice groups significantly increased: explanation, $F(2, 34) = 7.57, p < .01$; practice, $F(2, 34) = 4.37, p = .015$. This pattern of duplicate errors between

Session 1 and 7 appears to fit a quadratic model in that the mean number of duplicates falls and then rises again. ANOVA confirmed the reliability of this quadratic pattern, $F(3, 69) = 3.84, p = .01$. It is intended that these data will also be examined further using Binomial Logistic Models to gain a clearer understanding of the dynamics of children's erroneous strategies.

Discussion

The aim of the present research was to address: (1) whether current theories of explanation can be generalised to children's explanations of their own self-generated answers, and (2) the impact of self-explanation on the development of children's analogical reasoning skills. We found that self-explanation alone was not sufficient to aid the development of analogical reasoning to an equivalent standard as that which arose when provided with feedback. It appears, therefore, that feedback on responses is essential for the enhanced levels of analogical reasoning performance. Our results also provide support for a metacognitive processing account of the link between self-explanation, feedback and the development of analogical reasoning.

As expected, children's performance on the matrix completion task improved over the microgenetic sessions. Analysis revealed that children's skill developed in all conditions, apart from the control group. This indicated that there was no age-related change in the three-month testing period and that repeated exposure to the task (with questions to keep time spent on task equal across conditions) was itself enough to improve children's performance. The number of duplicate errors (i.e., those made when basing answers on perceptual features) was shown to decrease over the microgenetic period. This finding provides support for the relational shift hypothesis proposed by Gentner and colleagues (e.g., Gentner & Toupin, 1986; Ratterman & Gentner, 1998). This claims that children initially use perceptual features of items to select answers (thus making duplicate errors). The frequency of such errors decrease as children start to reason using relations between the matrix items (thus selecting more correct answers). We know that children who perform well are reasoning using relations between the items as this is the only plausible way that children can consistently select a correct answer.

In relation to the issue of whether children's explanations of self-generated answers was beneficial to the development of their analogical reasoning skills, our analysis indicated that the performance of children who provided explanations throughout the microgenetic training did improve significantly. However, the trends in the data indicate that improvement was not as pronounced as it was for the feedback or the explanation plus feedback groups, and also not much better than for the practice group. This pattern of results provides evidence that explanation alone is not the most successful method for encouraging children's understanding and that children benefit more from having feedback on their answers.

One of the most interesting findings of our study was that when children were no longer required to provide explanations the number of duplicate errors increased. It

seems that explanation has an effect *only* on immediate performance. This latter observation supports the proposals of Berardi-Coletta et al. (1995) who suggest that explanation guides participants to examine the underlying processes required for problem solving rather than the surface level features of the task. Our study has provided, to our knowledge, a unique situation whereby participants who were once asked to provide explanations no longer have to do so. Therefore, what we have added to Berardi-Coletta et al.'s suggestion is the notion that explanation alone does not provide a deep enough level of learning to generalise understanding to trials where explanation is no longer required. Our proposal has implications for researchers who believe that explanation aids the construction of complete mental representations (e.g., Chi et al. 1994; Pine & Messer, 2000). If explanation alone did create a more complete mental model, surely participants would be able to generalise such representations to very similar trials in which they did not have to explain?

Another finding that supports the metacognitive processing account of explanation is the impact of feedback. It is evident from the data that feedback is very useful in terms of the development of reasoning skills; indeed, the two groups who demonstrated the highest levels of learning both included a feedback element. This is interesting on two counts. First, it shows that children who received feedback reached a higher standard of reasoning than children who did not. A potential problem with the performance of the children in the explanation group was that some used the same sub-optimal explanations throughout the study (e.g., after selecting a duplicate response these children stated that they chose an answer 'because it was the same'). Without providing children with feedback, those who believe that their task is to find a matching item are less likely to update their strategies. Feedback may encourage children to engage in reflection on why their explanation was wrong and thereby to update their strategies. Second, the value of feedback ties in with existing research showing that children's explanations are beneficial. In particular, previous research has typically asked children to explain an answer provided by the experimenter. In such studies, children are actually being given *implicit* feedback in that they are told that the given answers are right or wrong. This may provide clues as to the correct strategy that should be adopted to solve problems.

Children who are given only feedback perform better than those who are only required to give explanations. However, being given feedback alongside explanation is even better. We propose that children are gaining additive benefits. First, they are told when they are wrong and can update their strategies accordingly. On top of this, they are benefiting from explaining - whereby they are more likely to attend to the task processes rather than the problem features. Both of these suggestions support the metacognitive processing approach that is based on the notion of strategy development and the optimisation of high-level cognitive processing.

In summary, the findings from this research have indicated that to encourage children to adopt a relational strategy in analogical reasoning they need to be provided with feedback as well as being asked to provide explanations. Some children who were asked to provide explanations gave explanations

which fit with a perceptual-similarity strategy and did so throughout the entire seven sessions. However, when asked to provide explanations alongside feedback children were more likely to update their strategy to one that was based on relations between items. These findings can connect the metacognitive processing approach to both explanation and the development of analogical reasoning skills. It seems that to make a complete relational shift children need feedback in their training.

Our research has provided an important contribution to both explanation and analogy research. The limitations of explanation have been recognised and from this it should be noted that assumptions about the usefulness of children's self-explanations should be made with care. The second important finding is that explanations, to be most useful, need to be combined with some kind of feedback, whether this comes in the form of explicit answers or indirectly, when children are asked to explain a correct or incorrect answer. Our results thus provide clear support for a metacognitive account of the roles of self-explanation and feedback in the development of analogical reasoning.

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