Learning trajectories in analogical reasoning : exploring individual differences in children's strategy paths

Pronk, C.M.E.

CHAPTER 6

General Discussion

To date, conclusions regarding the nature of changes in the ability to reason by analogy have frequently been drawn on the basis of results obtained from *cross-sectional* training studies (e.g., Chen, 1996). In contrast, the studies presented in this dissertation were designed to *microgenetically* investigate young children's inter- and intra-individual variable analogical learning trajectories over time. By providing children with repeated non-guided practice, dynamic-test-type training and transfer tasks, as well as applying specific methods and analyses, detailed accounts of changing strategic analogical performance were revealed. In this discussion, these accounts will be interpreted in accordance with Siegler's (1996, 2006) overlapping waves theory of cognitive change, along five dimensions: the source, rate, path, breadth and variability of change.

The Source of Change

Study results in this dissertation have pointed to several factors that appear to underpin and encourage changes in analogical reasoning. The overlapping waves theory refers to these factors as 'sources of change' (Siegler, 2006). The results sketched in the first three studies (Chapters 2, 3, and 4) clearly showed that repeated practice experiences are sufficient to prompt spontaneous progression in analogical performance on both geometric and figural analogical task, in children attending first and second grade. According to Siegler (2006), this type of change may be considered as natural because it does not arise from explicit interventions. The finding that practice alone was sufficient to activate the use of analogical strategies suggests that analogical reasoning skills must have been already present, albeit in a rather rudimentary form, in the repertoire of children of this age and that the opportunity to practice accelerated its spontaneous use (e.g., Tunteler & Resing, 2002, 2007a,b).

Nevertheless, training (in the form of a dynamic test) had a greater effect upon children's performance than repeated practice (see also, Resing, Xenidou-Dervou, Steijn, & Elliott, 2012). Interestingly, the data from the present study revealed different groups of learners. Some children benefited most when provided with either practice or training alone, while others gained most from a combination of practice and training. There were also other children for whom neither practice nor training appeared to make a difference to their analogical performance. These results confirm the suggestion of others that the acquisition and development of cognitive abilities may show differing pathways when acquired through instruction than through more 'natural' unprompted opportunities, making it essential to examine both in combination (Kuhn, 1995; Bjorklund, Miller, Coyle & Slawinsky, 1997; Opfer & Siegler, 2004). However, it was only training that appeared to influence first and second grade children's explained analogical strategy use to a significant extent (Tunteler & Resing, 2007a; Siegler, 2006, 2007).

The studies described in Chapters 3 and 4 also found that at the initial non-guided practice session, spatial working-memory (Ven, Boom, Kroesbergen, & Leseman, 2012; Rasmussen & Bisanz, 2005), but not verbal working-memory (e.g., St. Claire-Thompson & Gathercole, 2006), was positively related to complete analogical solutions and subsequent correct analogical explanations of those solutions. It was additionally discovered that spatial and verbal working-memory were unrelated to the overall number of transformations in behavioral solutions. It did not seem difficult for children to get the solutions partially correct although they struggled to achieve complete accuracy. This finding was in accordance with the proposition that (spatial) working-memory capacity is likely to place a limits upon completion of full analogical solutions, where several transformations need to be processed in parallel, until greater skill in the serial processing of transformations is reached (Halford, Wilson & Philips, 2010; Richland, Morrison, & Holyoak, 2006). The influence of spatial working-memory on the number of verbalized transformations might also explain why children beginning to discover a new strategy, and therefore encountering more demands upon their working-memory, initially appear unable to describe the correct strategies that they had used (Siegler & Stern, 1998).

The Rate of Change

The earlier mentioned sources of change were found to be closely related to children's rate of cognitive change. Siegler (2006) depicts the rate of change as the timeline and amount of experience related to development from initial to consistent adequate performance (rate of uptake). In Chapter 2, the qualitative analysis revealed that children in the practice condition gradually changed their analogical performance from incomplete to complete answers between the first two sessions. The short training, however, induced in some children a continuation of a gradual change in analogical performance, while others changed rather rapidly from completely associative responding to consistent analogical strategy use. These results provide evidence to support Siegler's observation (2006) that microgenetic studies tend to show a relatively large number of children going through a gradual change in their rate of discovery and generalization of a cognitive strategy, while a smaller number demonstrate a more rapid change. They also challenge any notion that analogical reasoning is an age constrained competence that cannot be induced by training in children that only show non-analogical, associative reasoning (Hosenfeld, Van der Maas, & Van den Boom, 1997b). Apparently, changes in analogical reasoning were already present in the cognitive processing abilities of these young children, but needed some prompting, in accordance with their zone of proximal development (Vygotsky, 1978). Furthermore, this increase in analogical performance persisted over a 3-month period for both conditions, revealing a rather rapid rate of up-take (Siegler, 2006). Apparently, changes in analogical reasoning obtained through experience or a short training procedure persists over a longer period of time, even when children are not given further training.

The subsequent quantitative studies in Chapters 3 and 4 confirmed these more gradual and rather rapid change trajectories. Multilevel Analyses for repeated measurements were applied in both studies, where children (Level-2) were nested in the repeated measurements (Level-1). In this manner, both individual and group variation were taken into account and could be displayed. This resulted in change trajectories (regression lines) for the individual children, as well as change trajectories (regression lines) for subgroups of these children based on systematic variation between background variables and experimental treatment (sources of change) (Van der Leeden, 1998). In the first, preliminary study with a smaller sample (Chapter 3), it was found that children displaying greater spatial working-memory capacity had a greater rate of change induced by repeated practice experiences alone. However, the rate of change induced by the dynamic-test-type training was unrelated to working-memory scores. After training though, children with a smaller spatial working-memory displayed a drop in analogical performance at the final session. However, this relatively small number of children per subgroup, a known drawback of microgenetic research (Siegler, 2006), did not permit us to arrive at comprehensive and strong conclusions and prevented us from adding additional background variables, such as variability in analogical strategy.

The study sample was therefore enlarged (Chapter 4). Like the former study outcomes (Chapter 3), individual developmental trajectories and rates of change generally displayed a fair degree of similarity within subgroups separated by the three analogical performance measures (complete analogical solutions, partial solutions measured by the number of transformations, and number of transformations cited by the child), as well as specific verbalized (non-) analogical strategy use. The rate of change within the subgroups was variable, both between and within children over sessions. For all performance measures, children with poorer initial performance tended to profit relatively faster from training than those who had displayed variable performance in their analogical reasoning. Nevertheless, in contrast with findings in Chapter 2, growth through training was followed by a dip at the final session for all subgroups, suggesting that not all the benefits of training were maintained. It is possible that the figural analogy tasks were more challenging than the geometrical items utilized in Chapter 2. Accordingly, children may have had greater difficulty citing certain transformations of the figural analogy tasks used in Chapters 3-5 than the geometric analogy tasks used in Chapter 2 (Sternberg & Rifkin, 1979), especially for higher ability children who might have switched from analytical to more heuristic problem solving (Klauer & Phye, 2008; Resing et al., 2012). Other contributory explanations for this dip could include the degree of children's motivation for tackling the tasks (Siegler & Engle, 1994), or the fact that the assessor did not provide feedback concerning the accuracy of children's answers (Siegler & Svetina, 2002).

The Path of Change

The path of change refers to developmental trajectories in terms of sequences of changing knowledge states and problem-solving behavior (Siegler, 2006). In this dissertation these sequences were investigated in accordance with Siegler's work (2007), which posited the benefit of trial-by-trial assessments of strategy use. In Chapters 2 and 4, a microgenetic, session-by-session assessment was employed in order to investigate variability in subgroup and individual children's use of analogical and non-analogical strategies and subsequent progress in a) their behavioral responses and b) the verbal explanations that they were able to offer for these.

In Chapter 2 various patterns of improvement in analogical reasoning were identified within the two conditions of first graders. Children showing a similar pattern of improvement were grouped together. These subgroups took varying routes in the acquisition of analogical strategies to solve geometric tasks. Children within subgroups performed more similarly to each other, but subgroups still displayed much variability both within and between children, indicating diverse and variable strategy use within as well as across trials. This finding is consistent with findings obtained from earlier studies using problem analogy tasks (Tunteler & Resing, 2002, 2007a,b).

With respect to the paths of change of the trained children in Chapter 2, the short training procedure had a particular effect on children's use of explicit correct analogical strategies (where they could verbalize their analogical solution strategies) and, to a lesser extent, on their use of incomplete analogical strategies. Interestingly, some children, who only gave associative responses prior to the short training procedure, improved their analogical reasoning performance more during the unprompted test sessions after the short training procedure than did their peers who had already showed some capacity for analogical reasoning prior to the short training procedure.

These results have important implications for education as it clarifies how 6-8 year old children from first grade can address logical operations on spatial objects through analogies. However, caution is needed in making claims as the data reported here originated from one experiment and the subgroups consisted of relatively small numbers of children. Further research investigating whether similar results can be obtained while instructing children of other ages, and with different types of analogies, will be necessary to strengthen or disconfirm these findings.

Underlying differences in strategy use were subsequently investigated in the study reported in Chapter 4. Here, subgroups were based on background variables, such as spatial working-memory. Inter- and intra-individual (analogical) strategy use of individual children within subgroups of learners could be displayed and specific strengths and weaknesses that influence particular learning trajectories were made apparent. Furthermore, several different verbalized strategies that were employed by the children, were identified.

As expected, children in both conditions displayed a greater variety of non-analogical and implicit analogical strategies before progressing to an increased number of implicit and explicit analogical solutions. This finding echoed those reported by Siegler and Svetina (2002). Children in their study also displayed a variety of non-analogical solutions to matrix analogies immediately before progressing to a situation where they were able to provide adequate solutions. However, this strategic behavior was not as common in their study as it was in the study described in Chapter 4.

In contrast with findings from the study reported in Chapter 2, in several cases, children reverted back to non-analogical strategies after training. At such times, they demonstrated greater variability in their use of non-analogical strategies than they had before training, or, instead, they started making up their own rules. Higher ability subgroups tended to use more of their own rules or simple 'don't know' explanations when reverting to non-analogical behavior during the final two sessions. As noted earlier in this discussion, this finding suggests that children may have (partially) shifted to a more heuristic form of strategy behavior that is quicker to execute, but which potentially reduces accuracy when tasks become more difficult than anticipated (Klauer & Phye, 2008; Resing et al., 2012).

Another interesting finding concerned some children in the lower ability groups who showed greater variability in their use of non-analogical strategies after training, but regressed to less variable, (possibly) less skilled performance during the final session. If caused by task difficulty (e.g., Halford et al., 2010), this indicated that a 'teachable moment' might have been lost between the final two sessions. Children may not have regressed, but rather progressed in their performance *if* they had received another training session between the final two sessions, in accordance with their zone of proximal development (Vygotsky, 1978; Alibali & Goldin-Meadow, 1993; Siegler, 2006).

The Breadth of Change

The breadth of change refers to transfer, to the generalization of newly acquired strategies to other contexts and problems (Siegler, 2006). For the transfer task described in Chapter 5, children were no longer required to solve figural analogies in a classical way of assessment, but instead were asked to take a more active role by constructing similar figural analogies for the examiner to solve. Although initial performance and progress on traditional analogical tasks predicted how well children would fare on the self-construction transfer task, particular partial performances (such as partial use of correct transformations), rather than complete solutions, were key to predicting this progress. This had been expected as other studies have shown that high-level mastery in analogical performance is needed to detect transfer of learning at this level (e.g., Siegler, 2006; Day & Goldstone, 2012).

It was notable that these partial construction measures were important even after initial capacity and working-memory had been held constant. Clearly, capacity for solving analogies is related to capacity to construct them as a few other studies have found (Harpaz-Itay et al., 2006; Bosma & Resing, 2006).). The relationship we found between spatial working-memory and analogy construction confirmed the findings of earlier studies (e.g., Rasmussen & Bisanz, 2005; Tunteler, Pronk, & Resing, 2008; Halford et al., 2010). Accordingly, children were better constructors, if they executed their analogical strategies (more) efficiently (Siegler, 2006). These outcomes indicate that children who progressed further in solving constructed response analogies, also acquired a more thorough or 'deeper' understanding of the underlying principles of the analogical tasks. After all, while constructing analogical tasks, children were required to extract earlier learned analogical relationships from schemas in their memory and could no longer rely on simply encoding these relationships from given analogical tasks (Perkins, 1992; Harpaz-Itay et al., 2006; Martinez, 1999).

Qualitative assessments of the self-construction tasks revealed that those children who were dynamically trained in solving figural analogies, explained a greater percentage of correct transformations and were more likely to refer to the more difficult types of transformations, such as orientation. Furthermore, although the greater number of analogies produced by children in the training condition at the transfer stage was not statistically significant, the children often provided qualitatively different explanations for these solutions. Where their constructed analogy was incorrect they often appeared to have created their own rules, rarely demonstrating the copying behavior of a complete novice, as was the case for many of the children in the practice condition (Sternberg & Rifkin, 1979; Siegler & Svetina, 2002). Evidence from the qualitative investigations suggests that the dynamic-test-type training was having an effect. However, for quantitative differences to emerge the length of training may need to be more extensive.

These self-generated analogies may have revealed children's previously acquired knowledge and experience, how deeply they had processed the material and consequently how much understanding they had gained of underpinning structural relations (e.g., Blanchette & Dunbar, 2000; Harpaz-Itay, Kaniel, Ben-Amram, 2006).

The variability of change

Siegler (2006, 2007) portrays the variability of change as referring to differences between children in the above-mentioned sources, rates, paths, and breadths of change, as well as changes within individual children's array of strategies. The various study outcomes described in this dissertation showed considerable inter- and intra-individual variability in the use of analogical strategies in both untrained and trained first and second graders. Siegler (2007) posits that such cognitive variability is an important variable in understanding, predicting, and describing the amount and type of cognitive change. Results described in Chapter 2 provide evidence for this position for the untrained group. Within this group, a natural increase in analogical reasoning was evidenced in children showing variable, diverse strategies on the first test session, whereas children demonstrating only non-analogical, associative reasoning did not change their performance over time. However, no conclusive evidence was found for the trained group. The short training procedure induced change in the analogical performances of both children initially showing variable analogical reasoning, and those showing only non-analogical, associative reasoning during the test session prior to the training session. Moreover, quantitative analysis at the group level showed that the short training procedure did not have a greater effect on children who displayed variable analogical reasoning, than on children not showing this kind of behavior. However, these results should be interpreted with caution, since the groups in this analysis were rather small and of unequal size.

In Chapter 4, results of children's initial variability in the use of analogical strategies, revealed a positive relationship between initial variability and increased analogical performance over time. This finding was possible due to the application of MLA, and the advantage this procedure has over the more traditional analyses utilized in Chapter 2. Using this method of analysis, it was also found that the dynamic-test-type training reduced the influence of initial variability. This outcome reflects the assumption that dynamic-test-type training should reveal children's 'true' potential, by making the test situation more equitable than static testing (Grigorenko, 2009). A longer dynamic-test-type training procedure, or more frequent dynamic training sessions, might have decreased the influence of children's initial performance further. This was confirmed by the qualitative findings where we saw children making rapid progress from little use of analogical reasoning to its more consistent use after training (see also, Tunteler et al., 2008).

Conclusion

Throughout this dissertation, inter- and intra-individual variable analogical reasoning was investigated both quantitatively and qualitatively. Specific strengths and weaknesses that influence particular learning trajectories were found, leading to insights that appear valuable for both the understanding of the nature of intellectual development and the prediction of children's learning trajectories to inform targeted education and educational interventions at an early stage (e.g., Grigorenko, 2009).

Dynamic testing may ultimately reveal particular forms of instruction, from metacognitive to more concrete (Resing, 2000), that are most powerful for children with different profiles. In addition, dynamic testing and working-memory assessment in combination may help to indicate the type of training or working-memory support most suited for an individual child (Morrison, Doumas, & Richland, 2011) although the current ability to offer classroom-based interventions for such difficulties remains sorely limited (Elliott, Gathercole, Alloway, Kirkwood, & Holmes, 2010).

Clearly, multiple sources of information are required to guide the design of high quality holistic, but targeted, education and educational interventions. In the current dissertation, a combination of open-ended figural analogical tasks, self-construction tasks and dynamic-test-type training proved sensitive for all ability groups, with evidence of variability being demonstrated at several levels. In addition, examination of several 'sources of change', and the use of several analogical and *non-analogical* outcome measures in subgroups of children may prove, as noted above, to be a valuable holistic means of measuring and predicting individual change trajectories, and so identify 'teachable moments' for particular children.

For example, it may be profitable for future research to investigate whether assessment should move beyond reliance upon the production of 'right or wrong' answers and, instead, give credit for partial answers and even 'inadequate' (non-analogical) strategies. A child moving from a single inadequate non-analogical strategy to using a variety of non-analogical strategies may be seen to have made progress and have benefited from training. It is also possible that children who create their own rules may be at a more advanced stage, and require different instructional emphases, than those who merely use 'copy' or narrative strategies. These outcome measures are less conventional, but perhaps important in their capacity to differentiate between children of lower ability. The number and type of transformations a child is able to provide may also prove a sensitive measure to help differentiate between high ability children. Future research should seek to verify these outcomes and, where appropriate, use this information to construct assessment batteries that are able to measure intellectual potential more broadly to better inform targeted educational interventions.

Further educational implications of the approaches outlined in this dissertation could apply to science education. Research indicates that analogical reasoning in science education is an important tool to help children deeply process and gain understanding of underpinning scientific principles and phenomena (e.g., Pittman, 1999; May, Hammer, & Roy, 2006; Haglund, Jeppsson, & Anderson, 2012; Blanchette & Dunbar, 2000). These studies, however, also indicated that eliciting children's self-generated analogies of newly introduced scientific principles could be associated with several challenges, such as drawing upon children's associative or narrative reasoning rather than their analogical problem solving. Future research should investigate similarities between children's (non-) analogical strategies found in the current dissertation and their (non-) analogical strategies utilized in generating analogies during science or other domains of education.

Within the field of educational psychology, there continues to be significant debate as to the value of cognitive assessment for the purposes of informing educational intervention (Fletcher and Vaughn, 2009; Reynolds and Shaywitz (2009), Compton, Fuchs, Fuchs, Lambert, and Hamlett, 2012; Hale et al., 2008; 2010; Fletcher et al., 2011). In the eyes of many educationalists and psychologists, psychometric tools and approaches have proven valuable for the purposes of selection, yet continue to offer little to help teachers for making informed decisions about how best to help individual children. It is surely incumbent upon educational and cognitive psychologists to devise more sophisticated approaches to understanding individual children's development, and to use this information to inform the design of powerful forms of instruction tailored to individual needs. The approaches outlined in the present dissertation represent an attempt to make progress in this direction.